| | L # | Hits | Search Text | DBs |
|---|---|---|---|---|
| 1 | L1 | 15 | (US-6357911-$ or US-6359267-$ or US-5743173-$ or US-5704411-$ or US-5385200-$ or US-4919950-$ or US-5033720-$ or US-3620294-$ or US-6509555-$ or US-5117613-$ or US-5708253-$ or US-5185513-$ or US-5397876-$ or US-5391862-$).did. or (JP-11054251-$).did. | USPAT; JPO |
| 2 | L2 | 1032337 | program$7 | USPAT; US-PGPUB; EPO; JPO; DERWENT |
| 3 | L3 | 14 | 1 and 2 | USPAT; US-PGPUB; EPO; JPO; DERWENT |
| 4 | L4 | 30238 | program$7 with tempera$5 | USPAT; US-PGPUB; EPO; JPO; DERWENT |
| 5 | L5 | 11 | 1 and 4 | USPAT; US-PGPUB; EPO; JPO; DERWENT |

| | L # | Hits | Search Text | DBs |
|---|---|---|---|---|
| 6 | L6 | 52579 | record$3 with tempera$5 | USPAT; US-PGPUB; EPO; JPO; DERWENT |
| 7 | L7 | 7 | 1 and 6 | USPAT; US-PGPUB; EPO; JPO; DERWENT |
| 8 | L8 | 86901 | record$3 same tempera$5 | USPAT; US-PGPUB; EPO; JPO; DERWENT |
| 9 | L9 | 0 | 1 and 8 not 7 | USPAT; US-PGPUB; EPO; JPO; DERWENT |
| 10 | L10 | 1 | record$3 and tempera$5 and 1 not 7 | USPAT; US-PGPUB; EPO; JPO; DERWENT |
| 11 | L15 | 300 | 219/667.ccls. | USPAT; US-PGPUB; EPO; JPO; DERWENT |

| | L # | Hits | Search Text | DBs |
|---|---|---|---|---|
| 12 | L16 | 297 | 15 not 1 | USPAT; US-PGPUB; EPO; JPO; DERWENT |
| 13 | L17 | 37 | 2 and 16 | USPAT; US-PGPUB; EPO; JPO; DERWENT |
| 14 | L19 | 22 | record$3 and 16 not 17 | USPAT; US-PGPUB; EPO; JPO; DERWENT |
| 15 | L21 | 238 | 16 not 17 not 19 | USPAT; US-PGPUB; EPO; JPO; DERWENT |

US-PAT-NO: 6357911

DOCUMENT-IDENTIFIER: US 6357911 B1

TITLE: Method and apparatus for predicting the equalized temperature of a food product

---------- KWIC ---------

Detailed Description Text - DETX (7):
To calibrate the series of infrared sensors it is necessary to **record** a minimum of five sets of **temperature** readings and the equalized **temperature**. The data is then supplied to a series of simultaneous equations set forth below in equation [1].

Detailed Description Text - DETX (11):
In a discrete process the readings of the infrared sensors are time tagged and **recorded** at specific times for a specific food item and after all four readings are taken for a specific food item the calculation of the equalized **temperature** begins.

US006357911B1

(12) **United States Patent**
**Groen et al.**

(10) **Patent No.: US 6,357,911 B1**
(45) **Date of Patent: Mar. 19, 2002**

(54) **METHOD AND APPARATUS FOR PREDICTING THE EQUALIZED TEMPERATURE OF A FOOD PRODUCT**

(75) Inventors: **Michele L Groen**, Piscataway; **Mark T. Grace**, Bridgewater, both of NJ (US); **David G. Wardle**, Walton-on-the-Hill (GB)

(73) Assignee: **The BOC Group, Inc.**, Murray Hill, NJ (US)

( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/464,978**

(22) Filed: **Dec. 16, 1999**

(51) **Int. Cl.**[7] ........................................ **G01K 7/00**
(52) **U.S. Cl.** ........................................ **374/169; 702/130**
(58) **Field of Search** ........................................ 374/163, 169, 374/164, 5, 50, 107, 102, 141; 99/443 R, 342; 702/130–136

(56) **References Cited**

U.S. PATENT DOCUMENTS

| | | | | |
|---|---|---|---|---|
| 4,854,726 A | * 8/1989 | Lesley et al. | 374/45 |
| 4,986,669 A | * 1/1991 | Yamaguchi | 374/107 |
| 5,066,141 A | * 11/1991 | Ikeda et al. | 374/169 |
| 5,259,389 A | * 11/1993 | Muramoto et al. | 128/736 |
| 5,392,031 A | * 2/1995 | Toriumi et al. | 374/169 |
| 5,683,605 A | * 11/1997 | Matsuoka | 374/107 |
| 5,738,441 A | * 4/1998 | Cambridge et al. | 374/102 |
| 6,076,964 A | * 6/2000 | Wu et al. | 374/141 |

FOREIGN PATENT DOCUMENTS

| | | |
|---|---|---|
| DD | 253 938 | 2/1998 |
| DE | 40 32 949 | 4/1992 |
| EP | 0 492 983 | 7/1992 |
| JP | 04 370068 | 12/1992 |

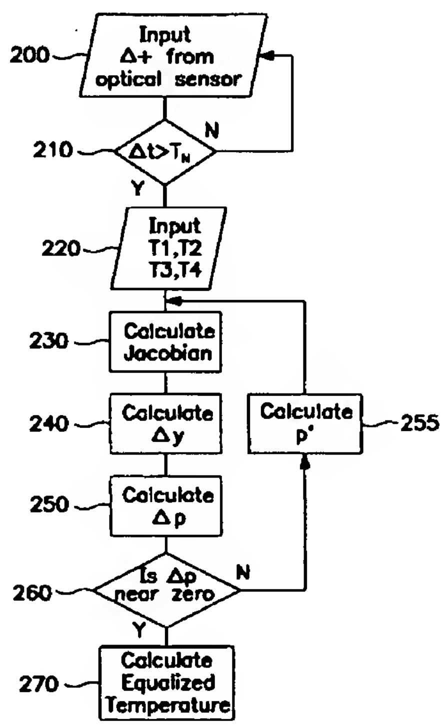
* cited by examiner

*Primary Examiner*—Diego Gutierrez
*Assistant Examiner*—Gail Verbitsky
(74) *Attorney, Agent, or Firm*—Joshua L. Cohen; Salvatore P. Pace

(57) **ABSTRACT**

In the processing of an item, particularly a food item, where the final equalized temperature is important to the processing a method and apparatus for predicting the equalized temperature is disclosed. A series of infrared sensors is used to measure the rate of change of the surface temperature of an item after the item is exposed to a known thermal shock such as heating or cooling. The predicted equalized temperature can be calculated from the series of surface temperatures using least squares, non-linear regression techniques. One means for applying a thermal shock to an item would be the use of cryogens such as liquid nitrogen, carbon dixoide snow or synthetic liquid air (SLA).

**19 Claims, 7 Drawing Sheets**



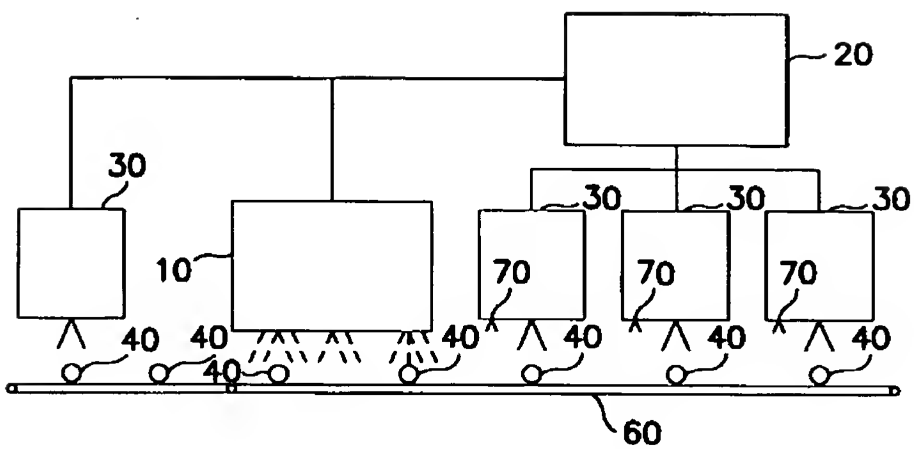



FIG. 1

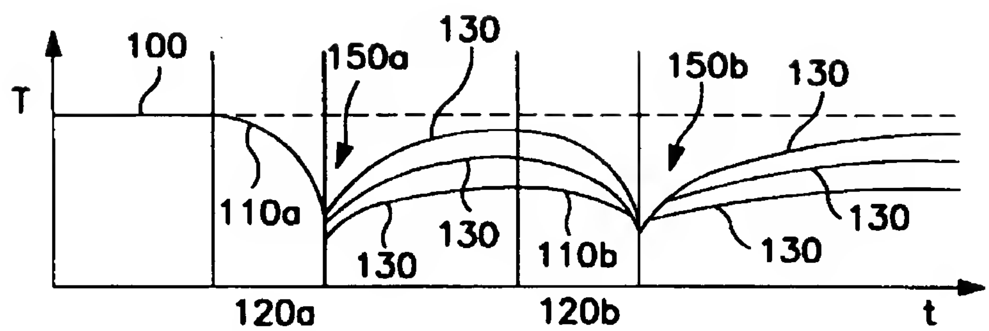

T
100
150a
130
150b
130
110a
130
130
110b
130
130
120a
120b
t

FIG. 2

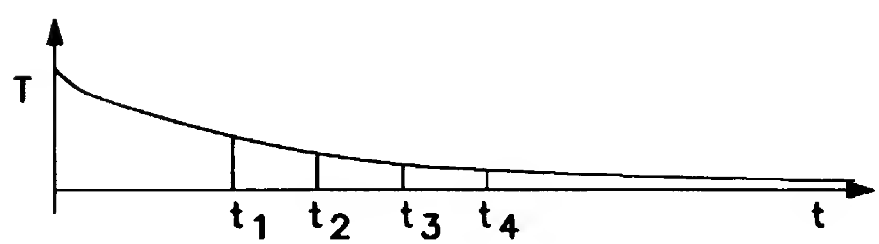

T
$t_1$
$t_2$
$t_3$
$t_4$
t

FIG. 4

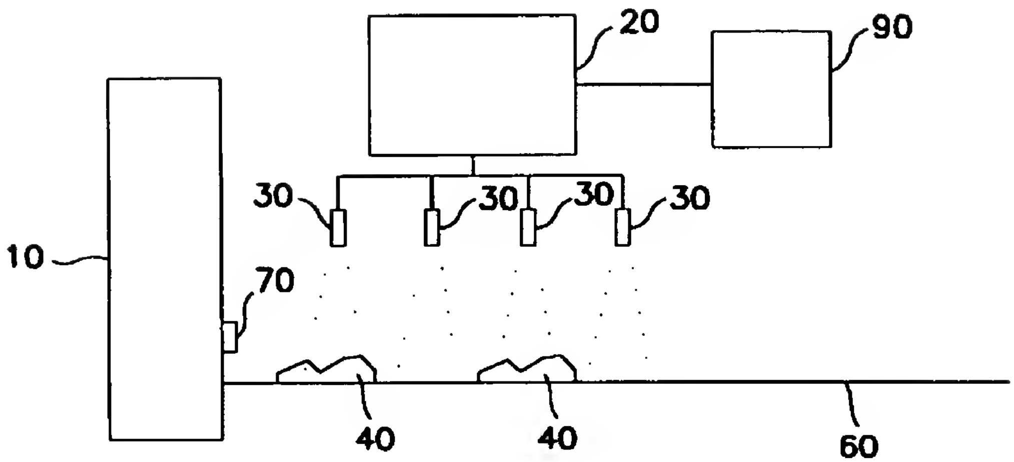



FIG. 3

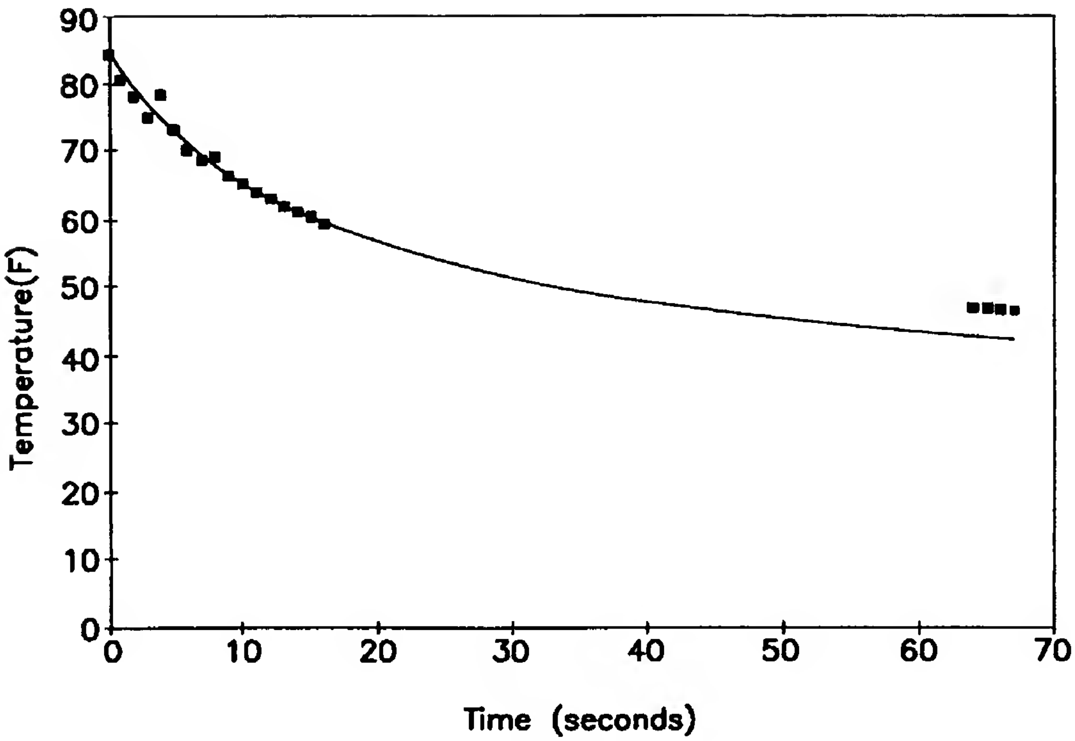

90
80
70
60
50
40
30
20
10
0
Temperature(F)
0
10
20
30
40
50
60
70
Time (seconds)

FIG. 5

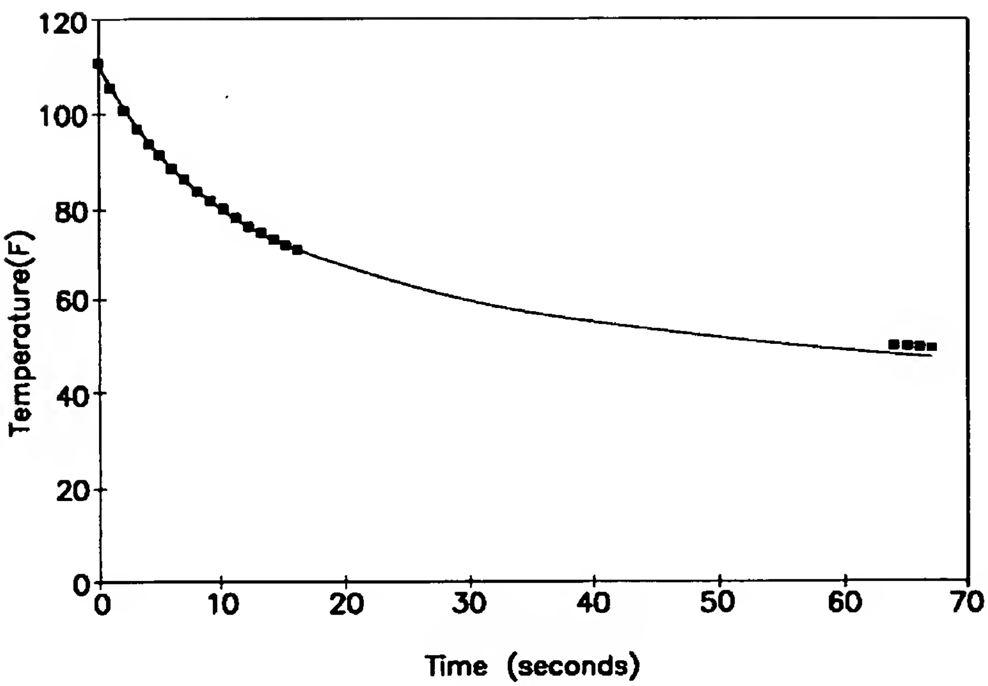

120
100
80
60
40
20
0
Temperature(F)
0
10
20
30
40
50
60
70
Time (seconds)

FIG. 6

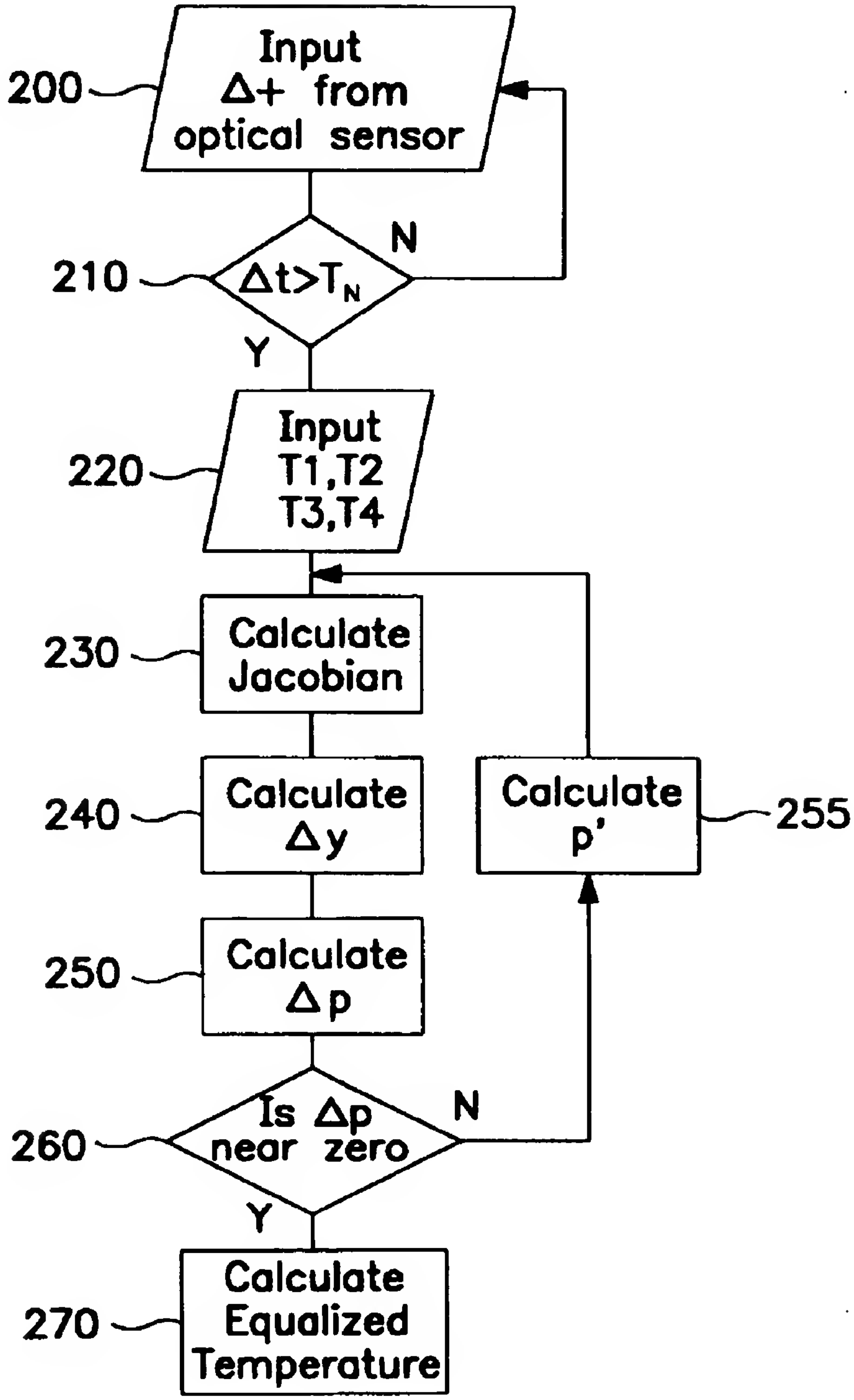

200
Input
Δ+ from
optical sensor
210
Δt>T_N
N
Y
220
Input
T1,T2
T3,T4
230
Calculate
Jacobian
240
Calculate
Δy
250
Calculate
Δp
255
Calculate
p'
260
Is Δp
near zero
N
Y
270
Calculate
Equalized
Temperature

FIG. 7

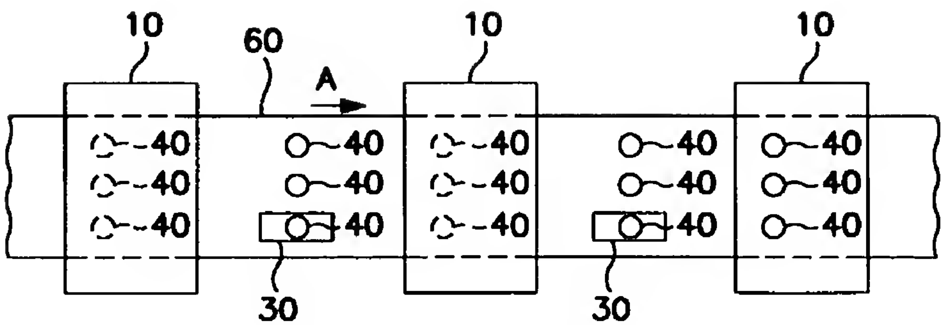

10
60
A
10
10
40
40
40
40
40
40
40
40
40
40
40
40
40
40
40
30
30

FIG. 8A

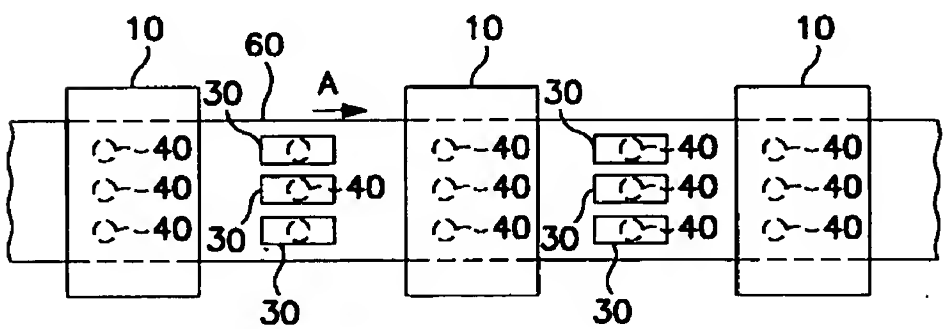

10
60
A
10
10
30
30
40
40
40
40
40
40
40
40
40
40
40
40
40
30
30
30
30

FIG. 8B

# METHOD AND APPARATUS FOR PREDICTING THE EQUALIZED TEMPERATURE OF A FOOD PRODUCT

## BACKGROUND OF THE INVENTION

The present invention relates to a method and apparatus for determining a prediction of the equalized temperature of a food product prior to the food product reaching its thermal equilibrium. More specifically, this invention is a method and apparatus for predicting such equalized temperature based on the response of the food product to thermal shocks.

The food industry produces a large quantity of standardized food products. In order to control the processes used to make standardized food products the industry is relying to a greater extent on electronic control systems which monitor various food manufacturing processes and input variables in order to control the quality of the food product as well as to minimize waste and decrease costs.

One problem associated with the processing of food items is determination of the equalized temperature of the food item. The need for temperature measurement is particularly acute in the area of food cooking and/or frying systems where high heat transfer rates result in a significantly hotter surface surrounding a cooler core. The goal is to reach a certain equalized temperature for the entire food item which takes a certain amount of time to achieve while also minimizing the amount of energy required to achieve the equalized temperature. Likewise, for cryogenically cooled or frozen foods there is a need to have food items reach a certain equalized temperature specified by the needs of the food item while using the least amount of cryogen.

An intrusive method of temperature determination such as the use of a temperature probe which is inserted into a food item has severe limitations in measuring the equalized temperature of a food item in a continuous food processing environment. The temperature probe must be manually inserted into a food item which cannot then be further processed resulting in waste. Also, the amount of labor needed to monitor a significant number of food items invasively would be cost prohibitive. Furthermore, the actual equalized temperature can only be measured after a certain amount of time passes, perhaps as much as ten or twenty minutes, and, therefore, a large number of food items could be incorrectly processed before an error in the equalized temperature is detected.

Another prior art method of temperature measurement such as a single infrared sensor would only be capable of measuring the surface temperature of the product and not the equalized temperature throughout the product.

In light of the foregoing, there is a need in the art for a method and apparatus which enables a food processor to predict or estimate the equalized temperature of a food item in a food processing line in a continuous manner without diverting actual food items from the processing line and using intrusive manual temperature testing. Furthermore, the method and apparatus need to allow the food processor to predict the equalized temperature of the food items immediately after a thermal shock is applied, i.e., cooking or cooling, , rather than after they have actually reached their equalized temperature, so that problems with the cooking process or cooling/freezing cryogenic process can be corrected in real-time.

## SUMMARY OF THE INVENTION

Accordingly, the present invention is directed to a method and apparatus for continuous prediction of the equalized temperature of a food item during processing.

Furthermore, the invention is directed to a method and apparatus for estimating such equalized temperatures in conditions of variable air flow and variable temperatures found in food processing.

In addition, the invention is directed to a method and apparatus which is non-intrusive and will not cause damage to food items.

To achieve these and other advantages and in accordance with the purpose of the invention, as embodied and broadly described herein, the invention includes an apparatus having an infrared sensor for measuring the surface temperature of a food item and means for applying a heat transfer shock of known quantity to the food item for a set length of time. At least two measurements of the surface temperature of the item are taken at specific times after the initial thermal shock and the equalized temperature of the food item is mathematically predicted from the two measurements.

In one aspect of the present invention the thermal shock and surface temperature measurement process is repeated in order to increase the accuracy of the predicted temperature.

In another aspect of the present invention multiple surface temperature readings are taken after each application of thermal shock with feedback mechanisms to alter the magnitude of the thermal shock.

In a further aspect of the present invention a plurality of infrared sensors are mounted over a food processing line so that food items pass under the plurality of sensors and an equalized temperature is predicted for a food item based on the readings from the plurality of sensors.

In a still further aspect of the invention the information as to the predicted equalized temperature of the food product is logged in a computer database for use by the food processing system and for purposes of altering the magnitude of additional thermal shocks to the food items.

It is to be understood that both the foregoing general description and the following detailed description are exemplary, and are intended to provide further explanation of the invention as claimed.

## BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are included to provide a further understanding of the invention and are incorporated in and constitute a part of this specification. The drawings illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention. In the drawings,

FIG. 1 is a diagram of an embodiment constructed according to the present invention.

FIG. 2 is a graph depicting the temperature curves resulting from the application of the embodiment of FIG. 1.

FIG. 3 is a diagram of a second embodiment of the present invention.

FIG. 4 is a graph depicting a plurality of temperature readings taken over time, t.

FIG. 5 is a graph depicting a first set of measured and calculated results.

FIG. 6 is a graph depicting a second set of measured and calculated results.

FIG. 7 is a flow diagram of the prediction method used in the present invention.

FIGS. 8A and 8B are top plan views of two possible embodiments according to the present invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings.

In accordance with the invention, an apparatus and method for the prediction of the equalized temperature of a food item is disclosed in FIGS. 1–7.

In FIG. 1 a diagrammatic representation of the an apparatus according to the present invention is depicted. Food items **40** placed on conveyer **60** travel under a first infrared sensor **30** which provides a measure of the surface temperature of the food item **40**. A thermal shock is applied to food items **40** through a means for providing a thermal shock **60** which could be a cryogenic sprayer for spraying liquid or vapor phase cryogen on food items **40** or an infrared heat source for heating food items **40**. One skilled in the art will realize that there are many means for providing a thermal shock to food items **40** including but not limited to infrared, microwave, inductive, convective or conductive heating and mechanical refrigeration or cryogenic cooling or freezing. Cryogenic cooling could be accomplished through the use of cryogens such as liquid nitrogen, carbon dioxide snow or synthetic liquid air (SLA). After receiving a thermal shock food items **40** are carried by conveyer **60** under a series of infrared sensors **30** which each provide a signal to controller **20** indicative of the surface temperature of the food items **40** over a period of time. This sequence of events can be repeated one or more times. The variation of the rate of temperature change can be used to indicate the predicted equalized temperature of the product. Controller **20** can use the data regarding the predicted equalized temperature of the food product or items in order to control the means for providing a thermal shock **10** to the food items **40**. Controller **20** could be a programmable logic controller (PLC) or other programmable computer such as a personal computer.

The process described in regard to FIG. 1 results in a graph similar to that of FIG. 2. Reading **100** represents the temperature of a food item prior to application of the thermal shock. During time periods **120a** a thermal shock is applied to the food items which is a cryogenic shock as depicted in FIG. 2 such that the temperature of the food item decreases as depicted in portion **110a** of the temperature versus time plot of FIG. 2. After application of the thermal shock a series of temperature readings **130** are taken by infrared sensors **30**. As expected the readings indicate a warming of the exterior of the food item over time as the heat from the warmer core of the food item is thermally transferred to the exterior of the item. An additional thermal shock during time period **120b** decreases the temperature of the food item **40** as seen in portion **110b** of FIG. 2. The difference in the rate of change of the temperature readings **130**, i.e., the difference between the slopes **150a** and **150b** is indicative of the core temperature of the product.

In FIGS. 3–4 a preferred embodiment of the present invention in which a means for applying a thermal shock is a cooker **10** which heats food items **40**. The food items **40** are then carried by conveyor **60** under a plurality of infrared sensors **30** which each provide a peak reading (T1, T2, T3, T4) for each food item. A plurality of optical sensors **70** are used to determine when a food item is passing under the infrared sensors **30**. Using a set of known factors which are product specific the final equalized temperature is calculated which can be supplied to a memory device **90** for use in the processing of the food items **40**.

To calibrate the series of infrared sensors it is necessary to record a minimum of five sets of temperature readings and the equalized temperature. The data is then supplied to a series of simultaneous equations set forth below in equation [1].

$$T1x_1+T2x_2+T3x_3+T4x_4=T_{equal} \qquad [1]$$

FIGS. **5** and **6** depict data from two sets of experiments comparing measured equalized temperatures with calculated equalized temperatures using the above method. The results show that the equalized temperatures can be predicted within +–5%.

FIG. 7 is a flow diagram of the method of predicting the equalized temperature of a food item. At steps **200** and **210** an input from optical sensor **70** indicates when a plurality of food items **40** has exited the means for providing thermal shock **10** and indicates that a plurality of reading T1, T2, T3 and T4 should be input from the infrared sensors **30** in step **220**.

In a continuous process the readings in step **220** are taken when the optical sensor indicated that the elapsed time since a food item has passed under the sensor is greater than the time necessary for the item to pass under all four infrared sensors **30** ($T_N$) for a given belt speed (BS). The peak readings of each infrared sensor **30** are then used to calculate the equalized temperature.

In a discrete process the readings of the infrared sensors are time tagged and recorded at specific times for a specific food item and after all four readings are taken for a specific food item the calculation of the equalized temperature begins.

Independent of the use of the continuous or discrete method of capturing the temperature readings T1, T2, T3, T4 from infrared sensors **30** the next step is to calculate the Jacobian (J) using three sets of data, time (matrix x), temperature readings T1, T2, T3 and T4 (matrix y) and a convergence criterion, matrix p. The temperature readings T1, T2, T3 and T4 as well as the time at which they were taken are known. The set of convergence criteria, p, is initially a guess which is continuously recalculated lo until the change in the convergence criteria is negligible. A non-linear regression algorithm based on a Taylor expansion is used where second and higher order terms of the model parameters are neglected on the condition that perturbation in those terms will be small. Thus the Jacobian is represented below in equation [2].

$$J=\begin{bmatrix} \exp\left(p_0+\frac{p_1}{\sqrt{p+x}}\right), & \frac{1}{\sqrt{p+x}}\cdot\exp\left(p_0+\frac{p_1}{\sqrt{p+x}}\right), & -\frac{1}{2}\cdot p_1\cdot(p+x)^{-3/2}\cdot\exp\left(p_0+\frac{p_1}{\sqrt{p+x}}\right) \\ x_1 & x_1 & x_1 \\ x_2 & x_2 & x_2 \\ x_3 & x_{:3} & x_{:3} \\ x_4 & x_{:4} & x_4 \end{bmatrix} \qquad [2]$$

After calculation of the Jacobian matrix J for a given set of temperatures, times and convergence criteria (the Jacobian matrix J will be different for different model assumptions) the next step **240** is to calculate the difference ($\Delta y$) between the experimental values for y and those predicted by the model using the following equation [3].

$$\Delta y = y - \exp\left(p_0 + \frac{p_1}{\sqrt{p_2 + x}}\right) \qquad [3]$$

In step **250** a set of corrections to originally predicted values for convergence criteria, p, is calculated using the following equation [4].

$$\Delta p = (J^T \cdot J)^{-1} \cdot J^T \cdot \Delta y \qquad [4]$$

If $\Delta p$ is near zero then the equalized temperatures may be calculated. If not, then a new set of convergence criteria is calculated in the $p' = p + \Delta p$. The calculation of the Jacobian matrix, J, and Ay is reiterated until $\Delta p$ approaches zero at which point the equalized temperature y can be calculated using equation [5].

$$y = \exp\left(p_0 + \frac{p_1}{\sqrt{p_2 + x}}\right) \qquad [5]$$

Although the present discussion and embodiments discuss a method of predicting the equalized temperature of a food item the process could be applied to non-food items which are heated or cooled and for which the final temperature of the item is important. The food or non-food items may be liquids, solids or mixtures thereof.

FIG. **8A** depicts the top plan view of a system according to the present invention in which food items **40** are conveyed on belt **60** in direction A. Food items **40** are subject to thermal shocks using a means for applying thermal shocks **10** which as stated above may be a cryogenic sprayer, mechanical refrigerator, fryer, cooker, inductive heating element, conductive heating or cooling element, convection heater, infrared heater or other heating or cooling means. A single infrared sensor **30** is placed so as to measure the temperature of one food, item across the width of the belt. FIG. **8B** depicts a top plan view of a similar system wherein a plurality of infrared sensors **30** are used to measure the temperatures of a plurality of food items across the width of the belt so as to insure that the food items across the belt are being processed in a like manner.

In a preferred embodiment of the present invention a first means for providing a thermal shock **10** would be a cooker, fryer or other heating means which would partially or fully cook a food item. A first Infrared sensor **30** placed after the first means for applying the thermal shock **10** enables the system to predict the equilibrium temperature of the food item **40** after cooking. This will then enable the controller **20** to regulate the amount of cryogen or mechanical refrigeration needed to cool and/or freeze the partially or fully cooked food item using the next means for applying thermal shock **10**. A series of means for applying thermal shocks **10** as heat interspersed by sensors **30** can be used to control the final hot temperature of food items **40** while minimizing the amount of thermal energy needed to achieve a desired end result. Likewise, a series of means for applying thermal shocks **10** as cold can be used to control the final temperature of food item **40** while minimizing the amount of energy needed to achieve the desired end result.

In such a cooking then freezing process it is possible to overheat the food thereby increasing the frying cost as well as the cost of energy required to freeze the product. For example where a product is overheated by 10 degrees Fahrenheit in a gas fired cooker where the product is being processed at 5000 pounds per hour it is estimated that the cost of the energy unnecessarily expended exceeds $12 per hour.



Although the present invention has been discussed with reference to a preferred embodiment, as will occur to those skilled in the art, numerous changes, additions and omissions may be made without departing from the spirit and scope of the present invention.

We claim:

1. An apparatus for predicting an equalized temperature of an item comprising:

means for providing a thermal shock to said item;

at least one sensor for determining a surface temperature of said item; and

means for predicting a value of the equalized temperature of said item from a rate of change of the surface temperature of said item after said thermal shock and before said item reaches the equalized temperature.

2. The apparatus of claim 1 further comprising a conveyor for moving said item from contact with said means for providing thermal shock.

3. The apparatus of claim 2 further comprising an optical sensor for determining when surface temperature should be determined using said at least one sensor.

4. The apparatus of claim 1 wherein at least one sensor is an infrared sensor.

5. The apparatus of claim 1 wherein said means for providing a thermal shock to said item applies cold to said item.

6. The apparatus of claim 1 wherein said means for providing a thermal shock to said item applies heat to said item.

7. The apparatus of claim 5 wherein said means for providing a thermal shock to said item applies a cryogen to said item.

8. The apparatus of claim 7 wherein the cryogen is selected from the group consisting of liquid nitrogen, carbon dioxide snow and synthetic liquid air.

9. The apparatus of claim 1 further comprising a means for storing a plurality of predicted equalized temperatures for a plurality of items.

10. The apparatus of claim 1 further comprising a controller for controlling is the means for providing a thermal shock to said item using at least one of the predicted equalized temperatures of said item.

11. The apparatus of claim 1 further comprising a second means for providing a thermal shock to said item and a controller for controlling said second means for providing a thermal shock using at least one of the predicted equalized temperatures of said item.

12. A method for predicting an equalized temperature of an item during processing of the item comprising the steps of:

applying a thermal shock to said item;

measuring a surface temperature of said item; and

calculating a predicted value for the equalized temperature of the item based on a first rate of change of the surface temperature of said item after applying said thermal shock and before said item reaches the equalized temperature.

13. The method of claim 12 further comprising the steps of: applying at least one additional thermal shock to said item to provide a second rate of change of the surface temperature of said item, and calculating another predicted value for the equalized temperature of the item based on the difference between said first and said second rate of change of the surface temperature of said item.

14. The method of claim 13 wherein the step of measuring comprises at east two measurements of the surface temperature of said item over time.

15. The method of claim 14 wherein said at least two measurements are taken at separate and discrete time intervals.

16. The method of claim 12 wherein the step of calculating the predicted value includes an algorithm based on least squares, non-linear regression techniques.

17. The method of claim 12 further comprising the step of: using the predicted value for the equalized temperature to control at least one of a magnitude and a duration of the thermal shock applied to said item.

18. The method of claim 12 wherein a first thermal shock is applied to said item using heat and the predicted value of the equalized temperature is used to control the temperature of the heat applied to said item.

19. The method of claim 14 wherein a first thermal shock is applied to said item using heat and the predicted value of the equalized temperature is used to control a duration that said item is subject to heating.

* * * * *

US005704411A

# United States Patent [19]

**Suzuki et al.**

[11] **Patent Number: 5,704,411**

[45] **Date of Patent: Jan. 6, 1998**

[54] **METHOD AND SYSTEM FOR HEATING INGOT FOR METAL INJECTION MOLDING**

[75] Inventors: **Atsushi Suzuki; Kazuya Sakamoto; Shinji Kazama; Nobumasa Hamazoe; Masayoshi Kai**, all of Sayama, Japan

[73] Assignee: **Honda Giken Kogyo Kabushiki Kaisha**, Tokyo, Japan

[21] Appl. No.: **621,839**

[22] Filed: **Mar. 22, 1996**

[30] **Foreign Application Priority Data**

| | | | |
|---|---|---|---|
| Mar. 22, 1995 | [JP] | Japan | 7-063196 |
| Mar. 24, 1995 | [JP] | Japan | 7-065957 |

[51] **Int. Cl.**[6] .......... **B22D 17/00**

[52] **U.S. Cl.** .......... 164/4.1; 164/113; 164/154.6; 164/900

[58] **Field of Search** .......... 164/4.1, 900, 71.1, 164/155.6, 154.6, 457, 312, 113

[56] **References Cited**

FOREIGN PATENT DOCUMENTS

5-285625 11/1993 Japan .

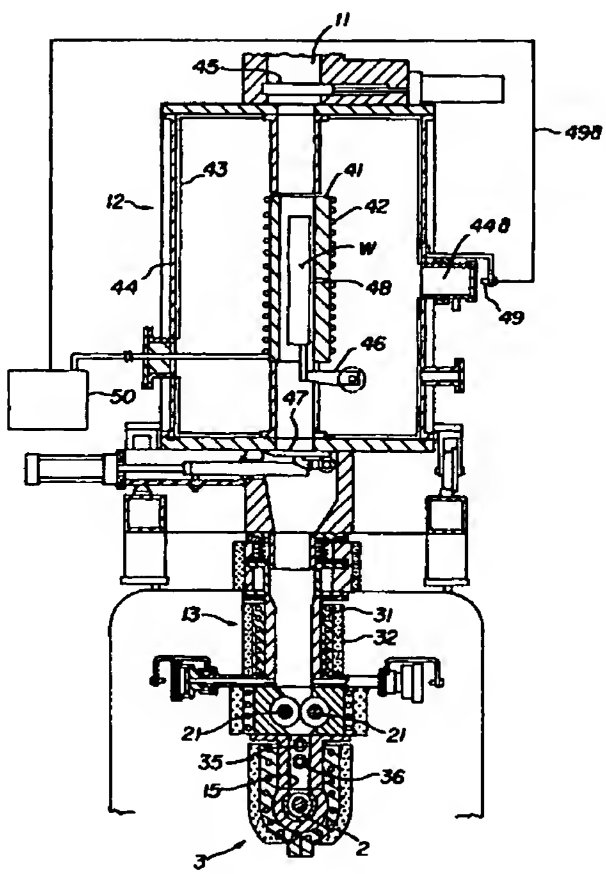
*Primary Examiner*—Kuang Y. Lin

*Attorney, Agent, or Firm*—Merchant, Gould, Smith, Edell, Welter & Schmidt, P.A.

[57] **ABSTRACT**

A method for heating a metal ingot for a injection molding comprising steps of finding out a time in advance relating to the time required for heating up to a set temperature in a test by using a thermocouple and a timer in a test furnace, of heating the ingot to the set temperature by heating it for that period of time in an actual furnace and of measuring a temperature at that time by a radiation thermometer to reserve the temperature based on the measurement. Further, it comprises steps of detecting an oxygen concentration within an atmosphere of the heating chamber after evacuating the heating chamber of the metal ingot to fill with an inert gas and of controlling power fed to an induction heating coil to heat the metal ingot when the detected oxygen concentration within the atmosphere is below a predetermined value.

**2 Claims, 10 Drawing Sheets**



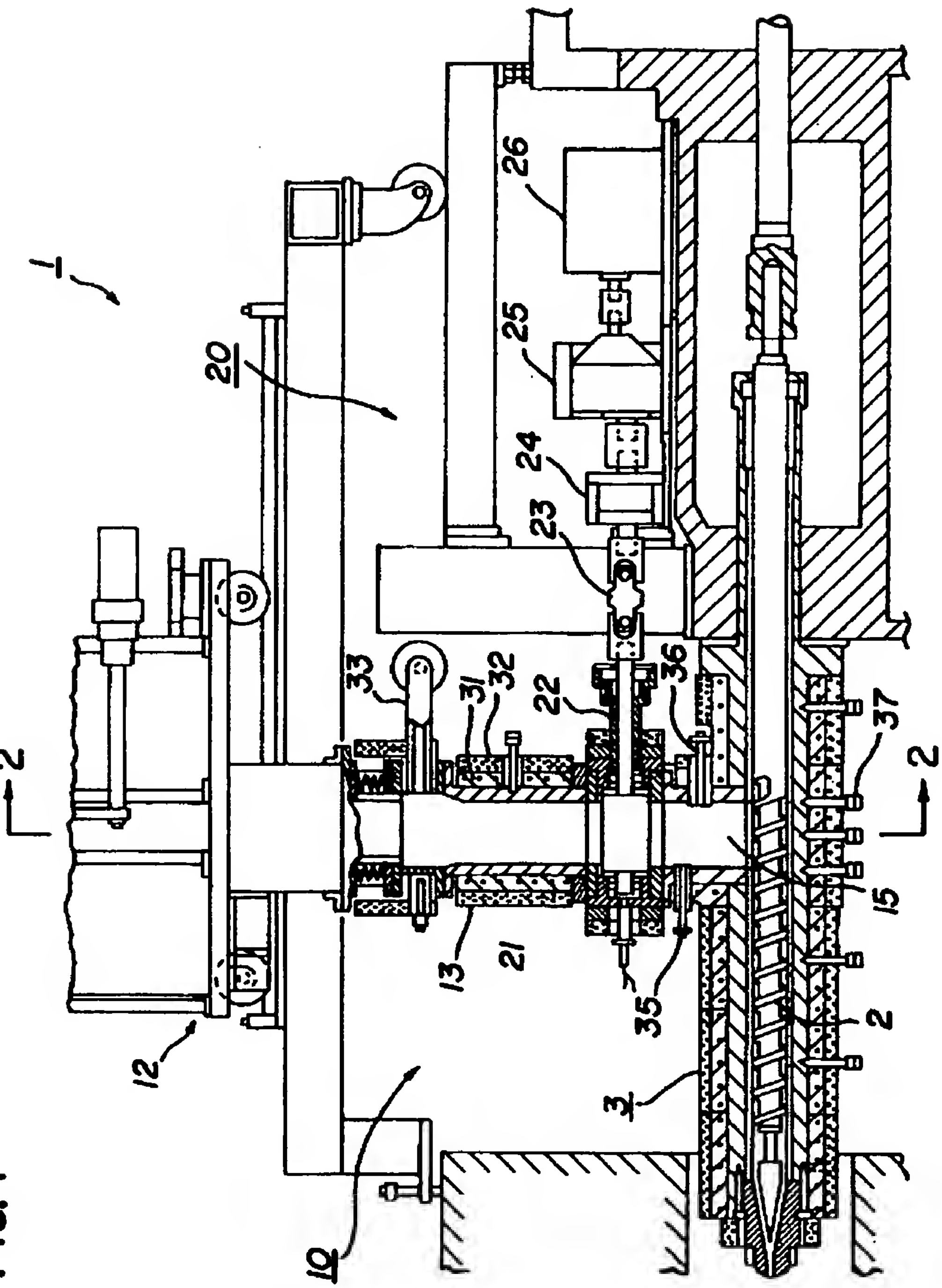



FIG. 1

FIG. 2

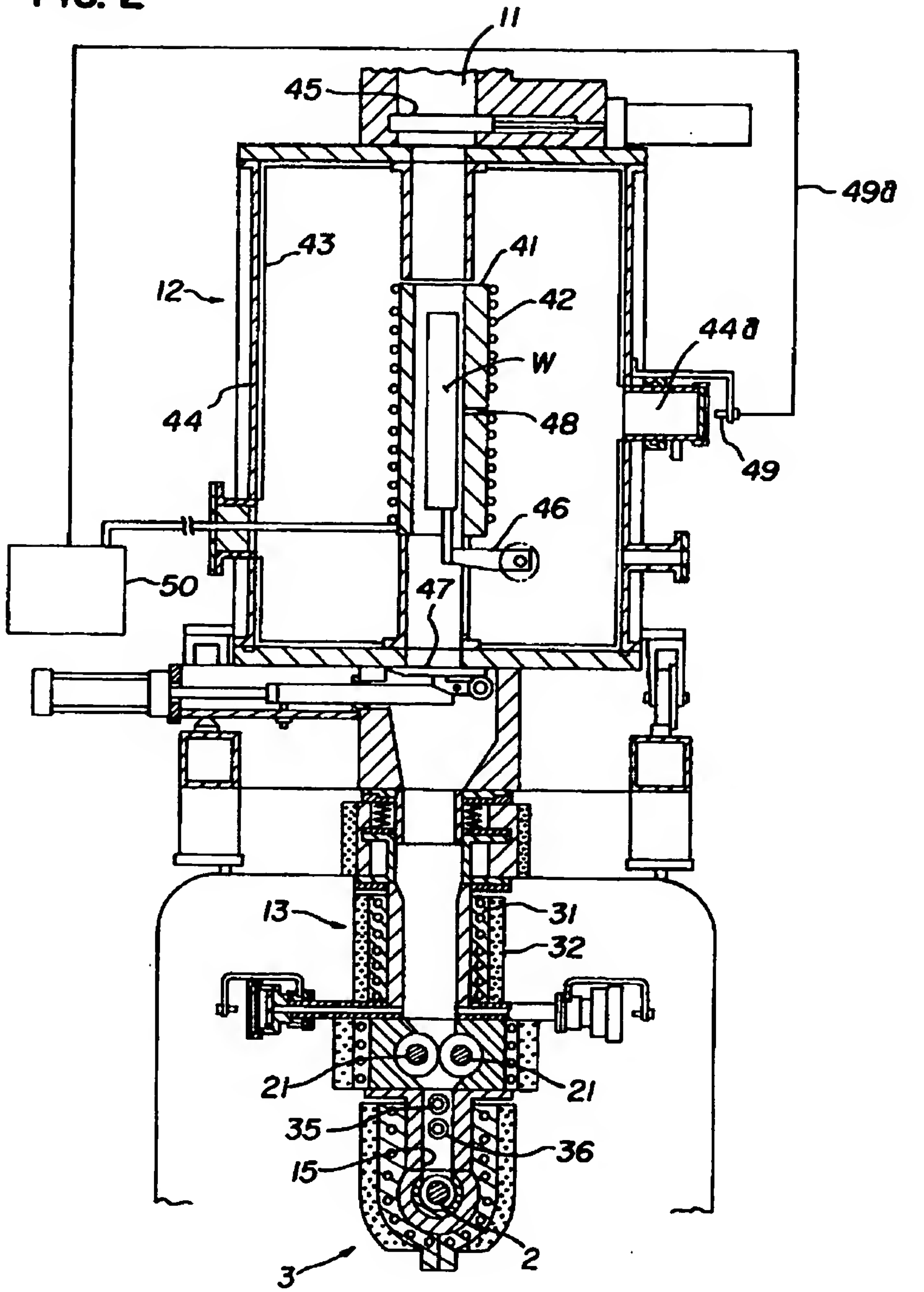


FIG. 3

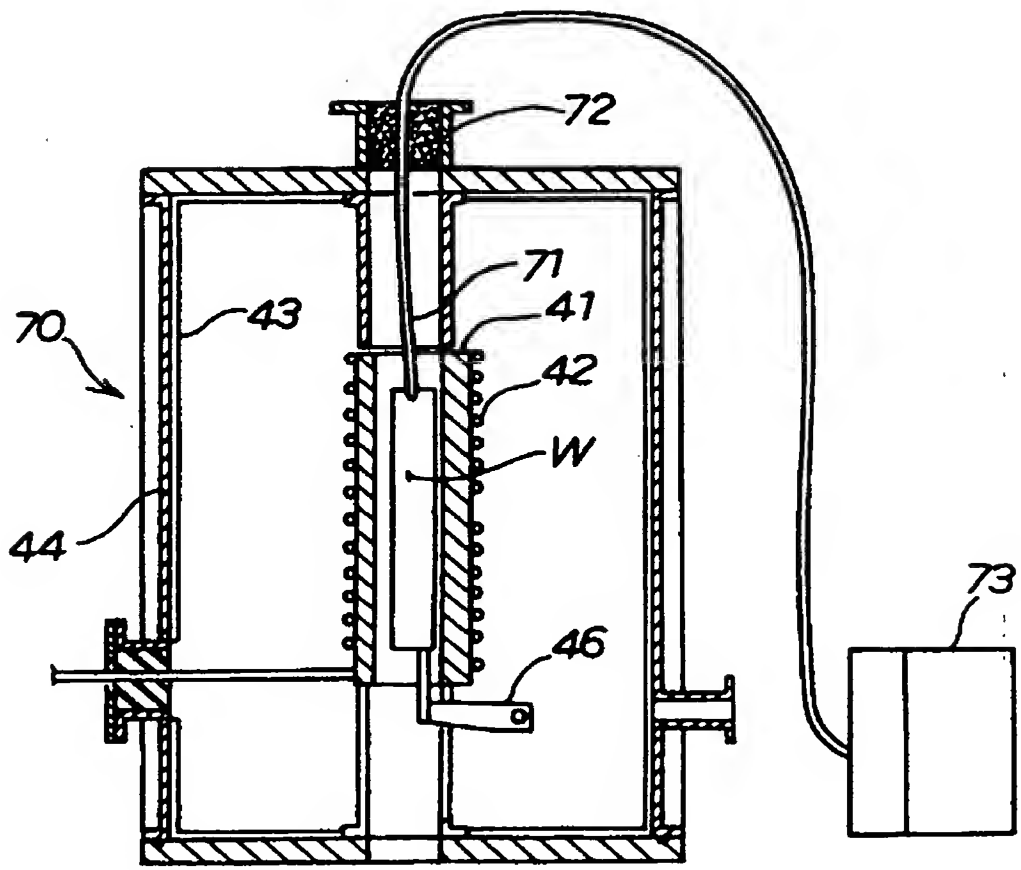


FIG.4

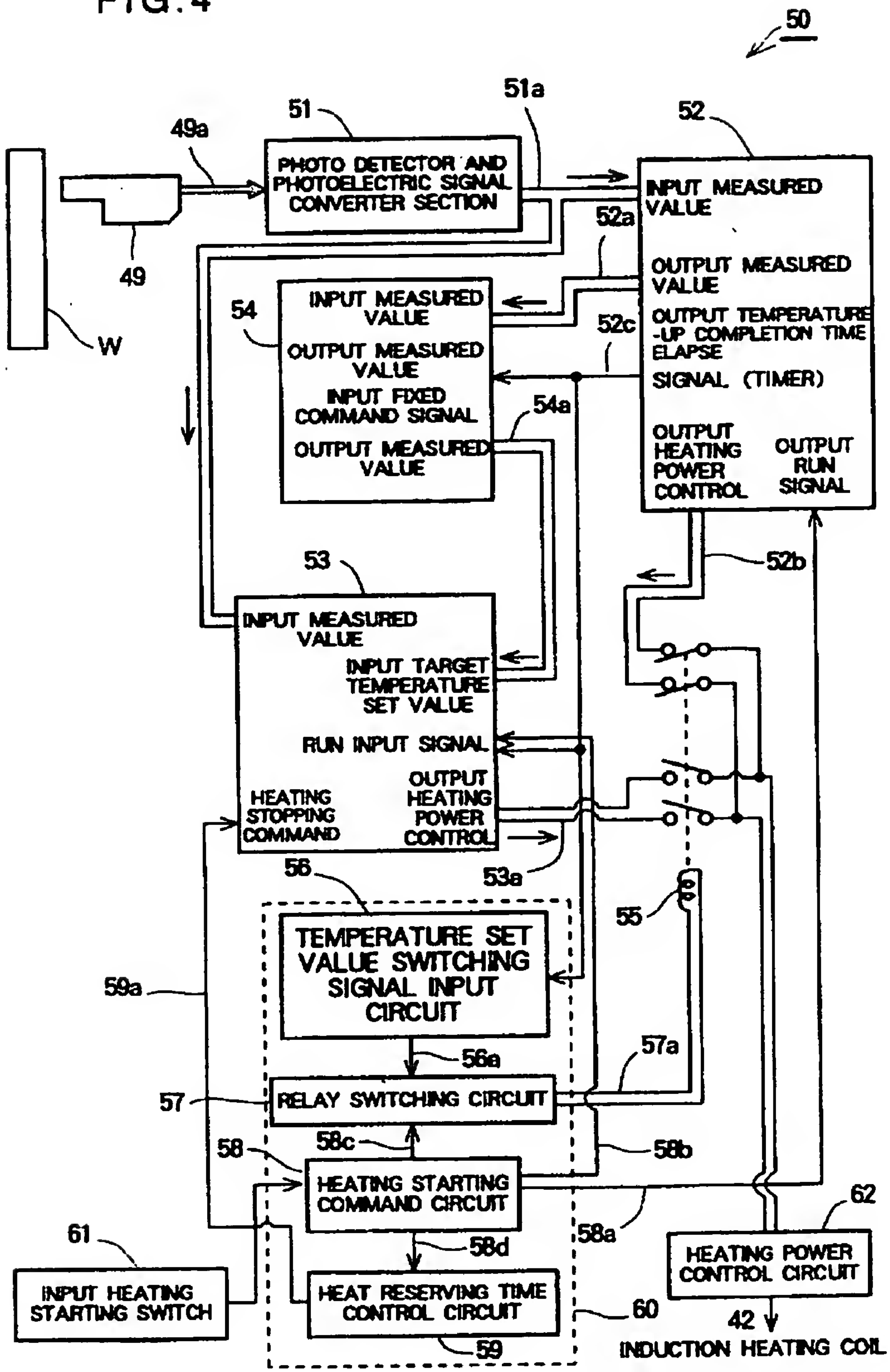

50
51a
51
52
49a
PHOTO DETECTOR AND PHOTOELECTRIC SIGNAL CONVERTER SECTION
INPUT MEASURED VALUE
52a
OUTPUT MEASURED VALUE
OUTPUT TEMPERATURE -UP COMPLETION TIME ELAPSE
SIGNAL (TIMER)
OUTPUT HEATING POWER CONTROL
OUTPUT RUN SIGNAL
49
W
54
INPUT MEASURED VALUE
OUTPUT MEASURED VALUE
INPUT FIXED COMMAND SIGNAL
OUTPUT MEASURED VALUE
52c
54a
52b
53
INPUT MEASURED VALUE
INPUT TARGET TEMPERATURE SET VALUE
RUN INPUT SIGNAL
HEATING STOPPING COMMAND
OUTPUT HEATING POWER CONTROL
56
53a
55
TEMPERATURE SET VALUE SWITCHING SIGNAL INPUT CIRCUIT
59a
56a
57a
57
RELAY SWITCHING CIRCUIT
58
58c
58b
HEATING STARTING COMMAND CIRCUIT
62
61
58d
58a
HEATING POWER CONTROL CIRCUIT
INPUT HEATING STARTING SWITCH
HEAT RESERVING TIME CONTROL CIRCUIT
60
42
59
INDUCTION HEATING COIL

FIG. 5

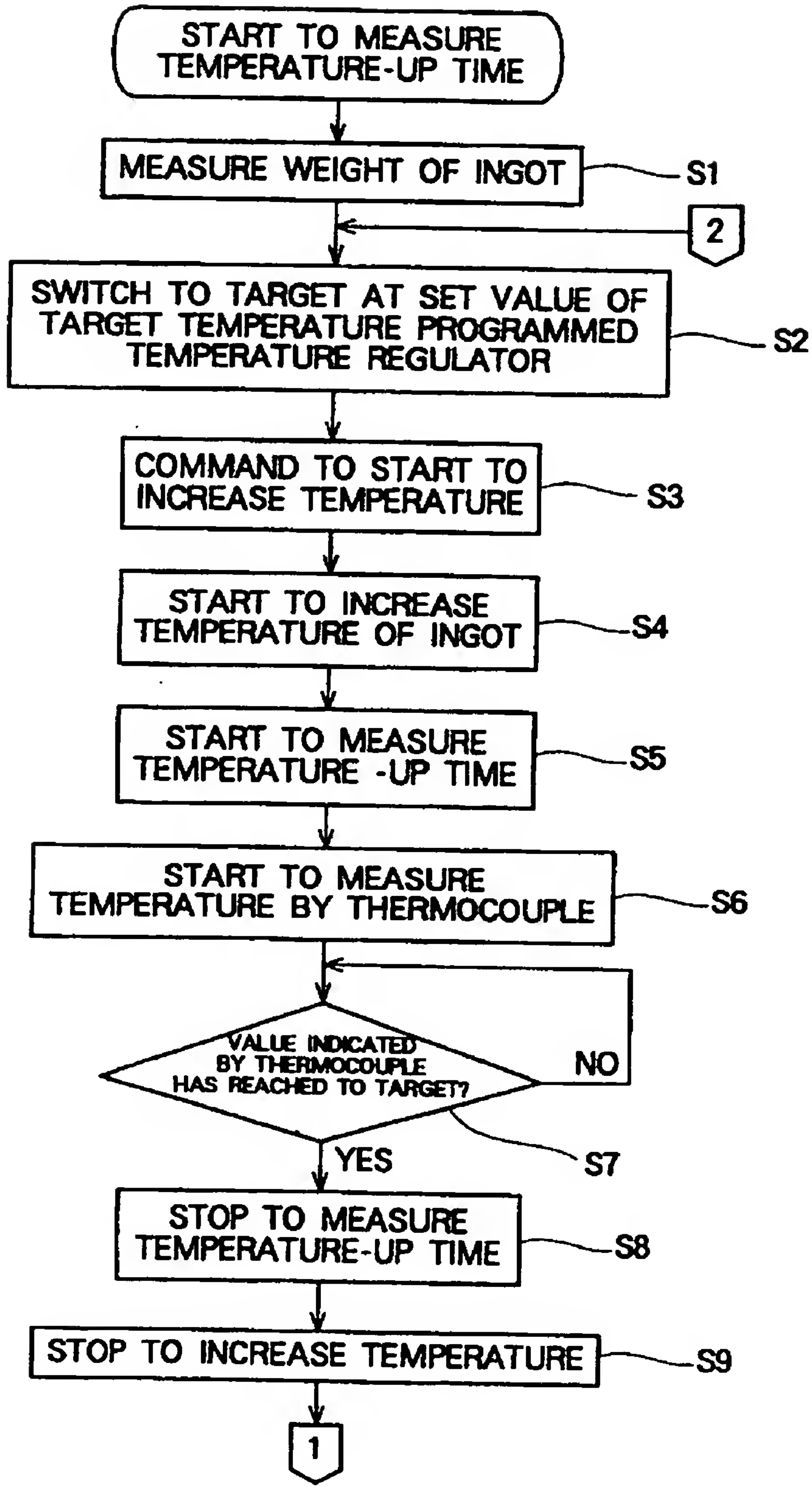

START TO MEASURE TEMPERATURE-UP TIME
MEASURE WEIGHT OF INGOT
S1
2
SWITCH TO TARGET AT SET VALUE OF TARGET TEMPERATURE PROGRAMMED TEMPERATURE REGULATOR
S2
COMMAND TO START TO INCREASE TEMPERATURE
S3
START TO INCREASE TEMPERATURE OF INGOT
S4
START TO MEASURE TEMPERATURE -UP TIME
S5
START TO MEASURE TEMPERATURE BY THERMOCOUPLE
S6
VALUE INDICATED BY THERMOCOUPLE HAS REACHED TO TARGET?
NO
YES
S7
STOP TO MEASURE TEMPERATURE-UP TIME
S8
STOP TO INCREASE TEMPERATURE
S9
1

FIG.6

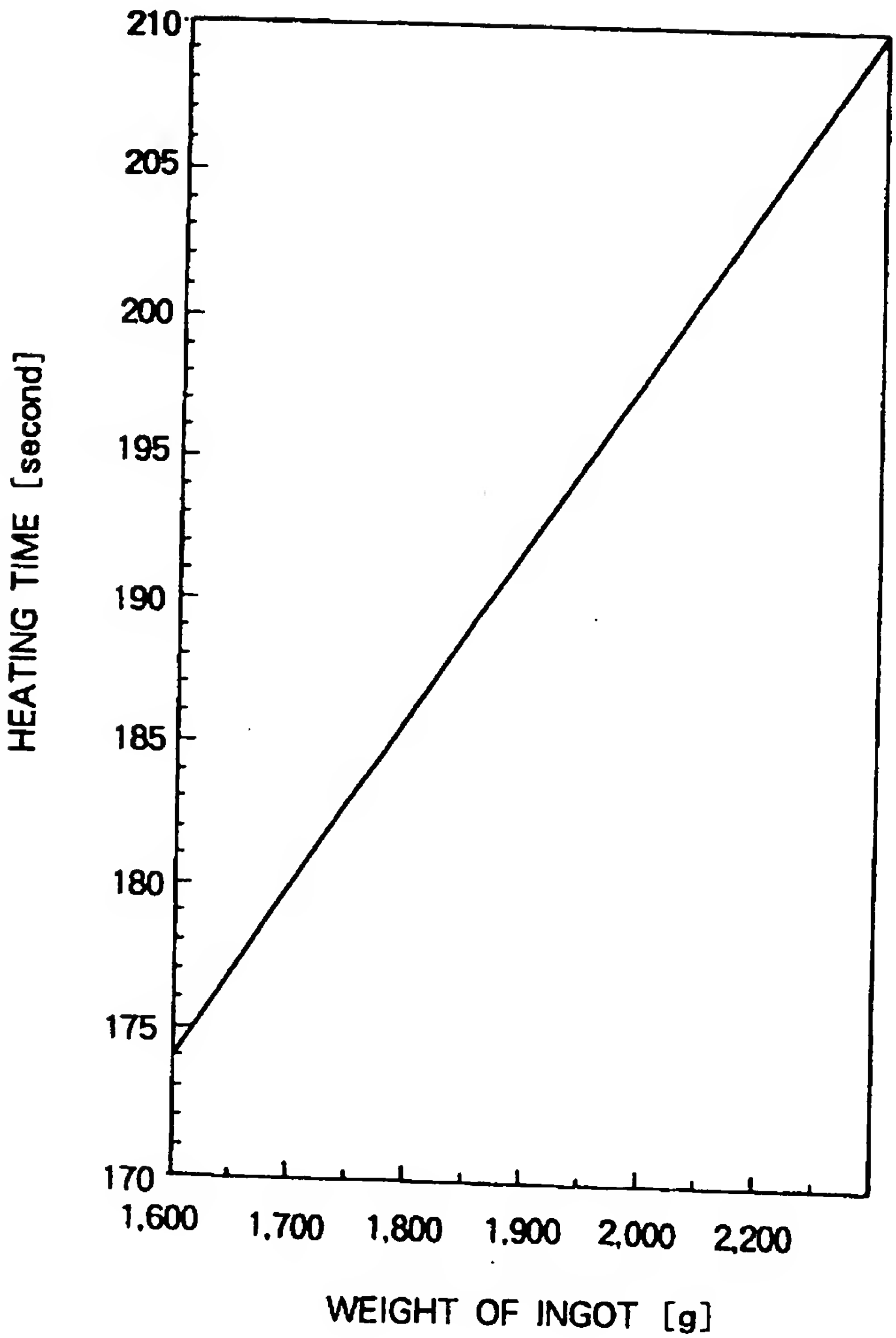
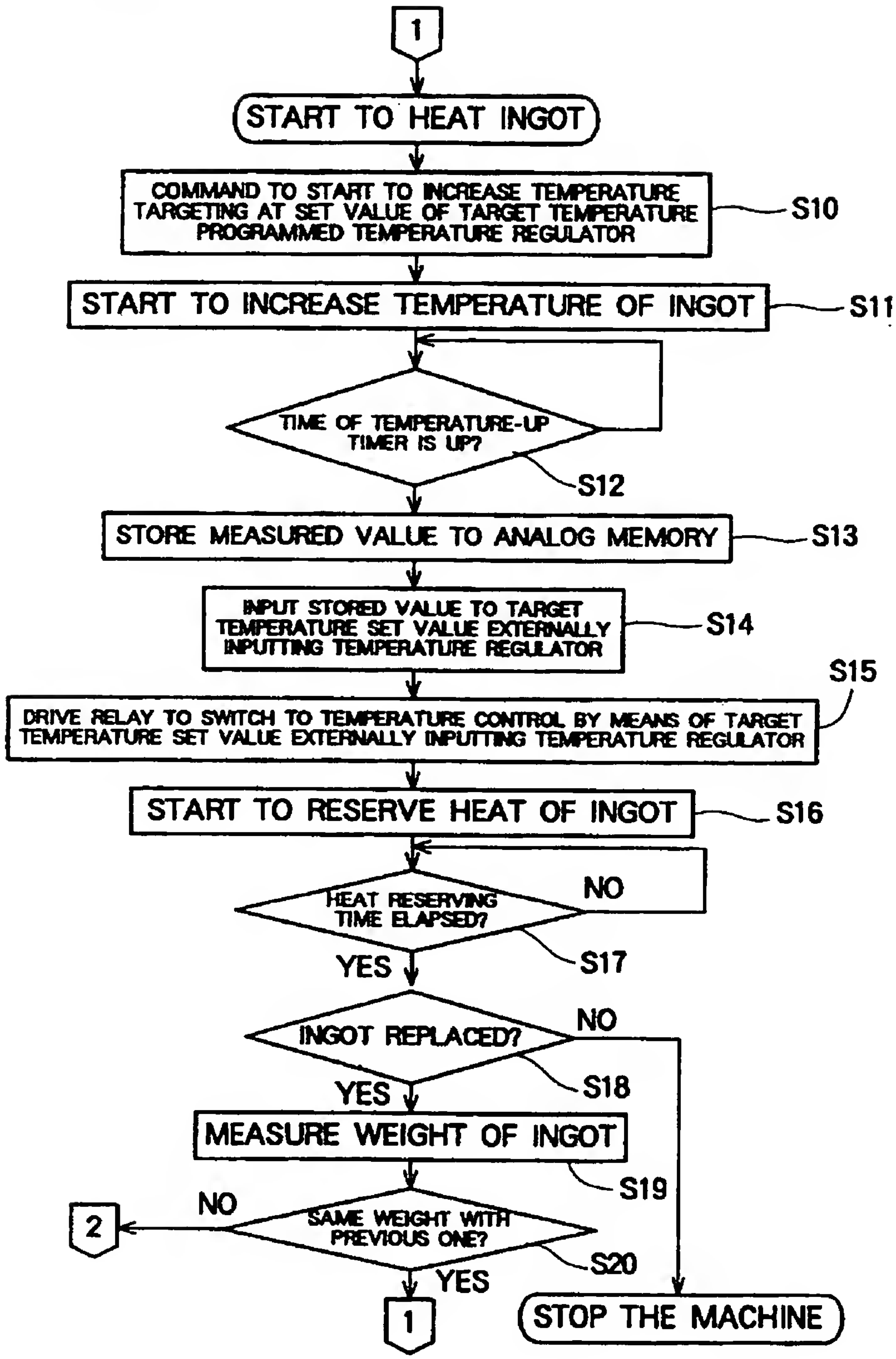

210
205
200
195
190
185
180
175
170
HEATING TIME [second]
1,600
1,700
1,800
1,900
2,000
2,200
WEIGHT OF INGOT [g]

FIG.7


1
START TO HEAT INGOT
COMMAND TO START TO INCREASE TEMPERATURE TARGETING AT SET VALUE OF TARGET TEMPERATURE PROGRAMMED TEMPERATURE REGULATOR
S10
START TO INCREASE TEMPERATURE OF INGOT
S11
TIME OF TEMPERATURE-UP TIMER IS UP?
S12
STORE MEASURED VALUE TO ANALOG MEMORY
S13
INPUT STORED VALUE TO TARGET TEMPERATURE SET VALUE EXTERNALLY INPUTTING TEMPERATURE REGULATOR
S14
S15
DRIVE RELAY TO SWITCH TO TEMPERATURE CONTROL BY MEANS OF TARGET TEMPERATURE SET VALUE EXTERNALLY INPUTTING TEMPERATURE REGULATOR
START TO RESERVE HEAT OF INGOT
S16
HEAT RESERVING TIME ELAPSED?
NO
YES
S17
INGOT REPLACED?
NO
YES
S18
MEASURE WEIGHT OF INGOT
S19
NO
2
SAME WEIGHT WITH PREVIOUS ONE?
S20
YES
1
STOP THE MACHINE

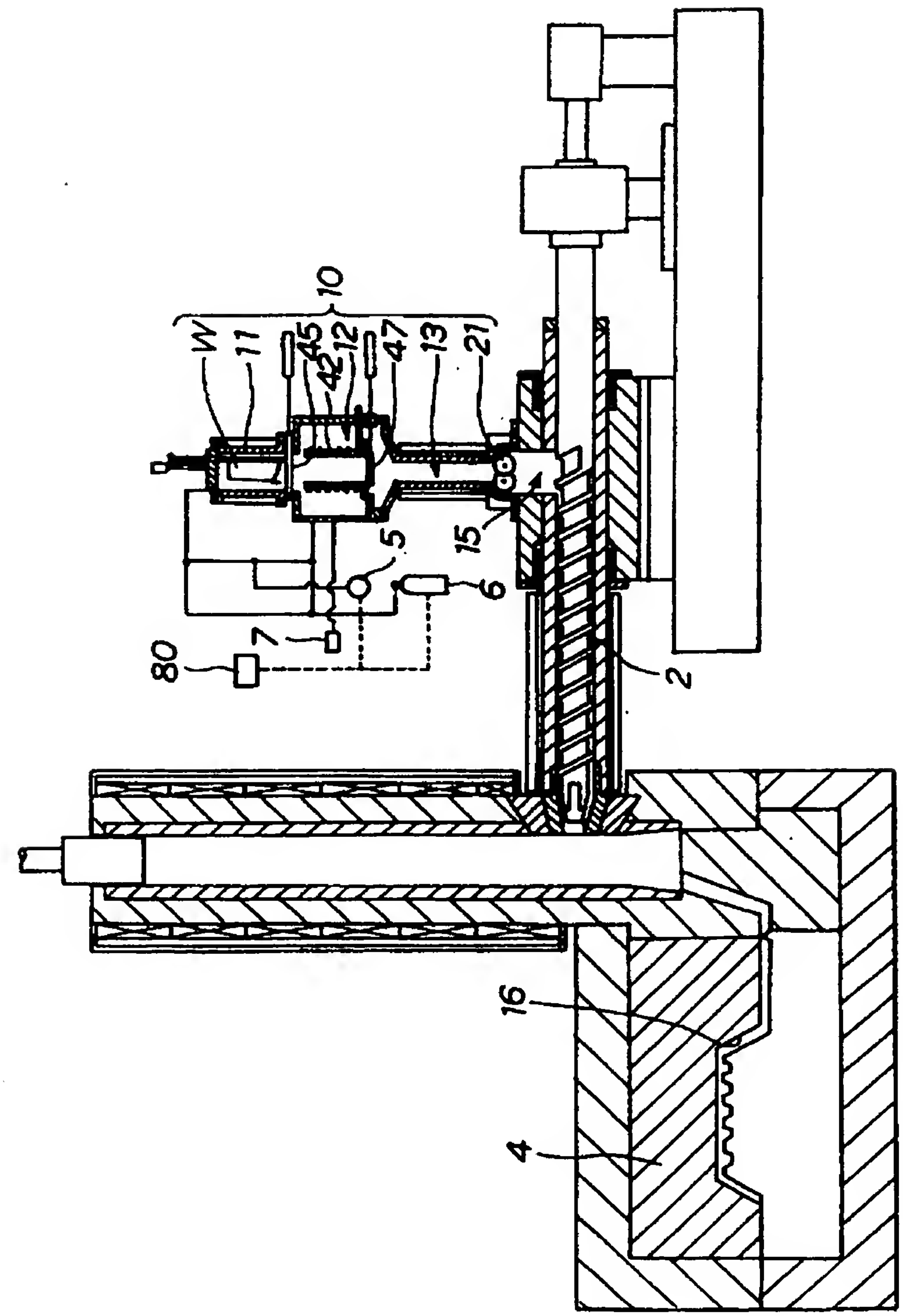



FIG.8

FIG.9

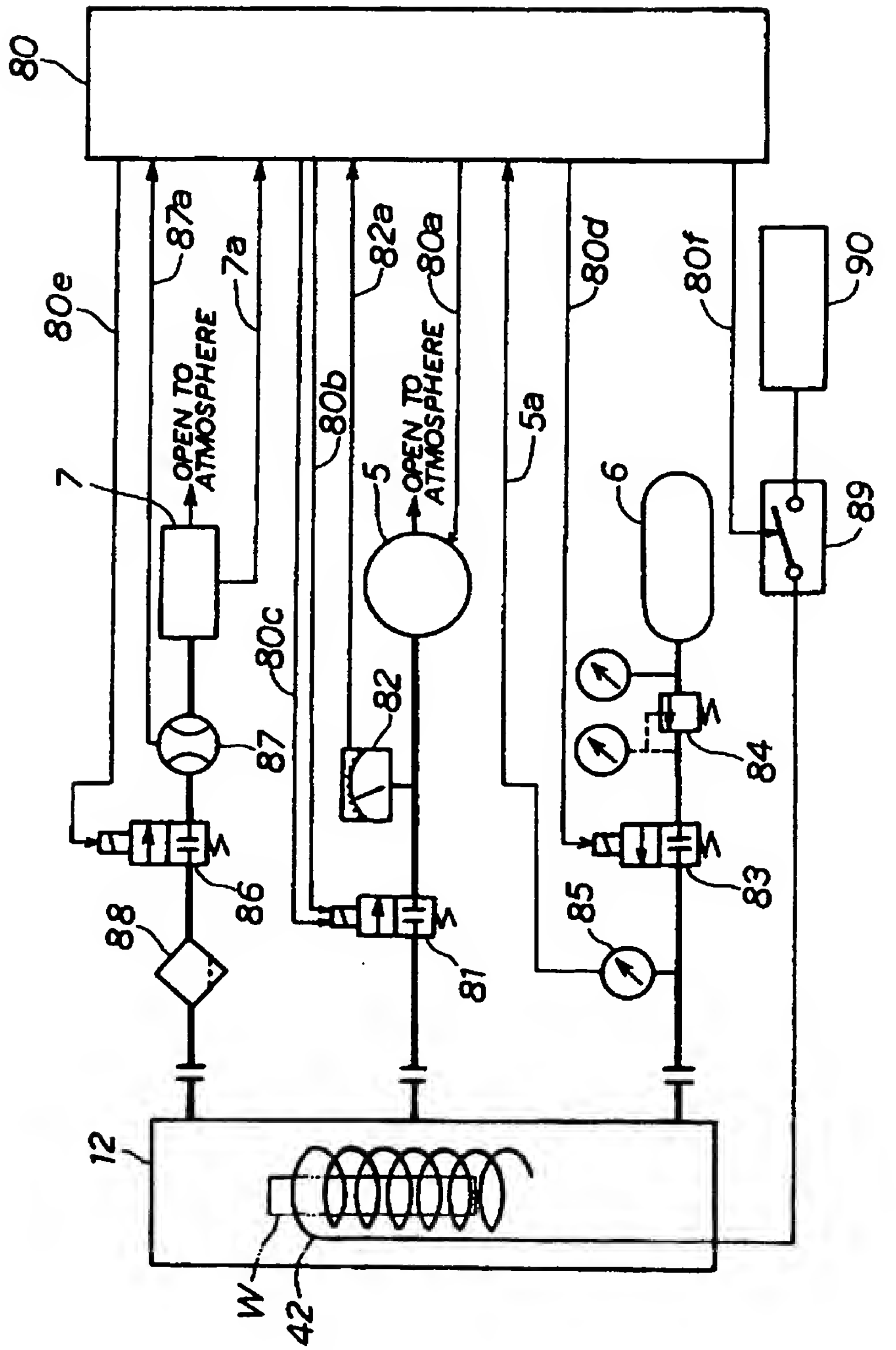
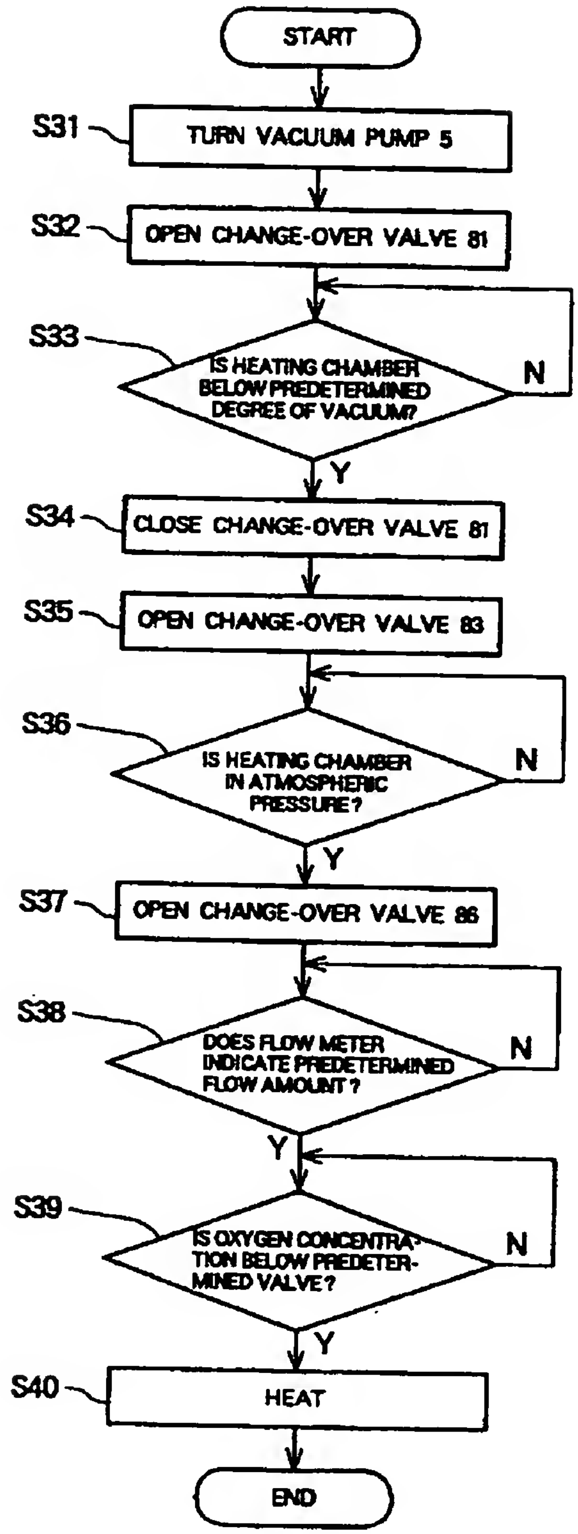

80
80e
87a
7a
82a
80a
80d
80f
90
OPEN TO ATMOSPHERE
7
80b
5
OPEN TO ATMOSPHERE
5a
6
89
80c
82
87
84
86
88
81
85
83
12
W
42

FIG.10


START
S31
TURN VACUUM PUMP 5
S32
OPEN CHANGE-OVER VALVE 81
S33
IS HEATING CHAMBER BELOW PREDETERMINED DEGREE OF VACUUM?
N
Y
S34
CLOSE CHANGE-OVER VALVE 81
S35
OPEN CHANGE-OVER VALVE 83
S36
IS HEATING CHAMBER IN ATMOSPHERIC PRESSURE?
N
Y
S37
OPEN CHANGE-OVER VALVE 86
S38
DOES FLOW METER INDICATE PREDETERMINED FLOW AMOUNT?
N
Y
S39
IS OXYGEN CONCENTRATION BELOW PREDETERMINED VALVE?
N
Y
S40
HEAT
END

# METHOD AND SYSTEM FOR HEATING INGOT FOR METAL INJECTION MOLDING

## BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method for heating an ingot for metal injection molding, in which a metal ingot is heated to a predetermined temperature and maintained at substantially that temperature, and to a metal heating system in which the generation of oxides is suppressed by detecting an oxygen concentration prior to heating.

2. Description of the Related Art

Upon heating an ingot of a magnesium (Mg) or aluminum (Al) alloy (hereinafter simply called "ingot") and maintaining the same at a given temperature, it is important to be aware of an accurate temperature of the metal ingot so as to provide a high quality mold. Thus, conventionally, arrangements have been made such that the temperature of the ingot, heated by an induction heater or a resistance heater, is measured by means of a radiation thermometer. Its temperature is brought up to a predetermined level by controlling the supply of power to the heater, and the temperature is maintained for a predetermined period of time. The radiation thermometer referred to herein represents an instrument for measuring an apparent temperature of an article by observing its thermal radiation.

However, because emissivity changes depending on shape, surface roughness and surface condition of an ingot, temperature represented by the radiation thermometer fluctuates. While a correct temperature may be found out by burying a thermocouple directly into the ingot and by measuring the temperature thereof, it must be removed from the ingot in order to crush the ingot in succession thereafter and it has been difficult to carry out such work in a consecutive process.

Hitherto, an inert gas is filled into the heating chamber in advance after evacuating it to prevent oxidation of the metal ingot in heating it. However, because a concentration of oxygen in the atmosphere of the heating chamber was not confirmed with that method, a defective molding was sometimes produced due to oxides generated by oxygen in the atmosphere. Another problem is that a magnesium or aluminum alloy, for example, may go up in flames.

## SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a method and a system which enable a metal ingot to be heated at a predetermined temperature without concern about dispersion of temperature indicated by the radiation thermometer while heating the ingot and while measuring the temperature thereof and which enable the temperature to be reserved thereafter with less fluctuation.

Another object of the present invention is to provide a method and a system which enable molding of the ingot safely, in addition to that is preventing defective moldings from being produced by suppressing oxide from being produced by detecting an oxygen concentration before heating the metal ingot.

According to a first aspect of the present invention, there is provided a method of heating an ingot for metal injection molding, in which an advance test is conducted in a test furnace of the same type as an actual furnace to detect, using a thermocouple and a timer, a time involved in heating the ingot up to a set temperature thereof, and then the ingot is heated in the actual furnace for the detected time until it reaches the set temperature, whereupon the temperature of the ingot is measured by means of a radiation thermometer for maintaining the ingot at the measured temperature.



According to a second aspect of the present invention, there is provided a metal ingot heating system comprising an oxygen sensor for sensing an oxygen concentration within an atmosphere of a heating chamber and a control circuit operable to energize an induction heating coil to heat the metal ingot when the sensed oxygen concentration within the atmosphere is lower than a predetermined value.

## BRIEF DESCRIPTION OF THE DRAWINGS

The specific nature of the invention, as well as other objects, uses and advantages thereof, will clearly appear from the description thereof and from the accompanying drawings, in which:

FIG. 1 is a sectional view of a main part of an injection molding apparatus to which an inventive method for heating an ingot of a metal injection molding is applied;

FIG. 2 is a sectional view taken along line A—A in FIG. 1;

FIG. 3 is a sectional view of a heating chamber as a test furnace;

FIG. 4 is a block diagram illustrating the arrangement of a control system of an induction heating control section;

FIG. 5 is a flow chart of a process for preparing a map in a preliminary test;

FIG. 6 illustrates an example of the map prepared in the preliminary test;

FIG. 7 is a flow chart of heating and heat reserving processes in an actual furnace;

FIG. 8 illustrates the overall arrangement of the injection molding apparatus to which an inventive metal ingot heating system is applied;

FIG. 9 is a block diagram illustrating the construction of the inventive metal ingot heating system; and

FIG. 10 is a flow chart explaining the sequential operation of the metal ingot heating system.

## DETAILED DESCRIPTION OF THE INVENTION

Referring to FIG. 1, an injection molding apparatus 1 is equipped with an injector 3 containing a screw 2 and a material supplying chamber 10 for supplying raw materials to the injector 3. The material supplying chamber 10 has, from top bottom thereof, an ingot introducing chamber 11 (see FIG. 2), a heating chamber 12 as an actual furnace, a heat insulating chamber 13 and a chopping chamber 15 equipped with choppers 21.

The heat insulating chamber 13 is surrounded by a heat reserving heater 31 and a cylindrical heat insulator 32, has a height for fully storing one ingot, and is connected with a vacuum and gas pipe 33 at the upper part thereof. Evacuation is carried out or an inert gas is supplied via the vacuum and gas pipe 33 by switching it.

The chopping chamber has a high-position level sensor 35 and a low-position level sensor 36 separated from each other in the direction of height thereof. Thermometers 37 for measuring a temperature distribution in the axial direction of the injector 3 are arranged in the axial direction.

The choppers 21 are head members of crushing means 20 and are connected to a motor 26 via a driving shaft 22, a swivel shaft 23, a biaxial gear case 24 and an decelerator 25. The biaxial gear case 24 is an output distributor having one

input axis and two output axes and the two choppers 21 are rotated in the opposite direction from each other by one motor 26.

In FIG. 2, the heating chamber 12 is a vacuum heating container having a cylindrical ceramic holder 41, an induction heating coil 42, a magnetic shielding material 43 and an outer cylinder 44. An upper shutter 45 is provided above the heating chamber 12, an ingot stopper 46 is provided within it and a lower shutter 47 is provided at the bottom thereof, respectively.

Further, provided on the outside of the heating chamber 12 is a radiation thermometer 49 for measuring a temperature of an ingot W, via an opening 48 perforated radially through the holder 41 and a radiant heat outlet 44*a* formed on the outer cylinder 44, and for outputting a signal 49*a* which corresponds to the measured temperature. The radiation thermometer 49 is connected with an induction heating control section 50.

The induction heating control section 50 is connected to the induction heating coil 42 to control power fed to the induction heating coil 42 based on the signal 49*a* from the radiation thermometer 49.

FIG. 3 is a section view of a heating chamber of a test furnace, wherein the same reference numerals denote the corresponding parts in the heating chamber 12. The heating chamber 70 of the test furnace has the same shape, volume and material with the heating chamber 12 of the actual furnace. While temperature of the ingot W is measured by using the radiation thermometer 49 in the heating chamber 12, it is measured by using a thermoelectric thermometer 71 utilizing a thermocouple in the heating chamber 70. A material and a wire diameter which will not be affected by the induction heating are used for the thermoelectric thermometer 71.

Essentially, one end of the thermoelectric thermometer 71 is inserted in the ingot W via an upper opening of the heating chamber 70 closed by a glass wool 72 and the other end thereof is connected with an indicator. Then, although not shown, the induction heating coil 42 is controlled by the induction heating control section in the same manner as the case of the actual furnace.

FIG. 4 is a block diagram illustrating the construction of a control system of the induction heating control section 50.

The induction heating control section 50 comprises a photo detector and photoelectric signal converter section (hereinafter referred to as a signal converter section) 51, a target temperature programmed temperature regulator (hereinafter referred to as a programmed temperature regulator) 52, a target temperature set value externally inputting temperature regulator (hereinafter referred to as an externally inputting temperature regulator) 53, an analog memory 54, a sequencer 60 and a relay 55.

The signal converter section 51 receives via an optical fiber 49*a* light output from the fiber radiation thermometer (radiation thermometer 49) which has measured a temperature of the ingot W and converts the light into an electrical signal to be output as a measured temperature signal 51*a*.

The programmed temperature regulator 52 receives the measured temperature signal 51*a* as a measurement and outputs it to the analog memory 54 as a measured temperature signal 52*a*. A timer (not shown) is provided within the programmed temperature regulator 52. It starts to time when a heating starting command signal (RUN signal) 58*a* is input in heating and reserving a temperature in the actual furnace and is reset when a time t1, found out based on a map (described later) prepared in advance, elapses. It is noted that the timer is reset in the initial state.

After receiving the heating starting command signal 58*a* and starting to time, the programmed temperature regulator 52 compares a time being timed by a PID adjustor or the like with the heating time t1 found out from the map and controls power fed to the induction heating coil 42 by outputting a heating power control signal 52*b* through heating power control means 62 composed of a relay and the like for example until when the temperature reaches to the heating time t1. When it reaches to the heating time t1, the programmed temperature regulator 52 outputs a temperature-up time elapse signal 52*c* to the analog memory 54. The analog memory 54 is composed of an A/D Converter, a digital memory and a D/A converter for example. Receiving the temperature-up time elapse signal 52*c*, it stores a measured temperature signal 52*a* at that time as a target temperature T1 and outputs it as a measurement signal 54*a* to the externally inputting temperature regulator 53.

The externally inputting temperature regulator 53 compares the measured temperature signal 51*a* with the measurement signal 54*a* by a PID controller or the like, computes a degree to be corrected and outputs a heating power control signal 53*a* to the heating power control means 62 to control the power fed to the induction heating coil 42 so that the target temperature T1 is attained. Further, when the externally inputting temperature regulator 53 receives a stop command signal 59*a*, it controls the heating power control means 62 through the heating power control signal 53*a* so as to stop the power fed to the induction heating coil 42.

The sequencer 60 performs a sequential operation corresponding to the test furnace (in preparing the map) and the actual furnace (in heating and reserving temperature) and comprises a temperature set value switching signal input circuit 56, a relay switching circuit 57, a heating starting command circuit 58 and a heat reserving time control circuit 59.

The temperature set value switching signal input circuit 56 outputs a switching command signal 56*a* when it receives the temperature-up time elapse signal 52*c* to the relay switching circuit 57.

When the relay switching circuit 57 receives the heating starting command 58*c* from the heating starting command circuit 58 or the switching command signal 56*a* from the temperature set value switching signal input circuit 56, it outputs a feeding command signal 57*a* for switching the programmed temperature regulator 52 and the externally inputting temperature regulator 53 to a relay 55.

When an ingot heating start switch 61 for heating the ingot is turned ON, the heating starting command circuit 58 outputs the heating starting command signals 58*a* and 58*c* to connect the programmed temperature regulator 52 to the heating power control means 62. When a heating start command signal 58*b* for reserving heat is output, it outputs the heating start command signal 58*c* to the relay switching circuit 57 to connect the externally inputting temperature regulator 53 to the heating power control means 62 and outputs a heating starting command signal 58*d* to the heat reserving time control circuit 59.

A timer (not shown) which starts to time when the heating starting command signal 58*d* is input and is reset when a preset time, e.g., three hours, has elapsed is provided within the heat reserving time control circuit 59. When such time elapses, the heat reserving time control circuit 59 outputs a stop command signal 59*a* to the externally inputting temperature regulator 53.

Operations for preparing the map described above and for heating the ingot and reserving the temperature thereof will be explained below.

FIG. 5 is a flow chart in preparing the map in a preliminary test, wherein S1 through S9 denote each step of the sequential operation.

The map is prepared based on the measurement made in the heating chamber of the test furnace constructed as described above before the heating/heat reservation is carried out in the actual furnace and shows a relationship between a heating time until when the ingot is heated up to the set temperature and a weight of the ingot. It is noted that reference will be made to FIGS. 3 and 4 as necessary.

The weight of the ingot W is measured at first in setting a temperature-up time in the test furnace in Step S1. Based on the weight of the ingot, the process is switched so as to target at the set value of the heating time of the programmed temperature regulator 52 in Step S2. The command for starting heating is issued as a heating switch is turned ON in Step S3. Power is then fed to the induction heating coil 42 by the heating command signal and the ingot W is started to be heated in Step S4.

When the temperature begins to be increased, a time needed to reaching the target set temperature is measured by using a stop watch for example in Step S5. At the same time, the temperature of the ingot W begins to be measured by means of the thermoelectric thermometer 71 in Step S6 and when an indicated value of the indicator 73 shows the target set temperature in Step S7, the measurement of the time is stopped in Step S8 and the power fed to the induction heating coil 42 is stopped to stop heating the ingot W in Step S9. The time measured in Step S8 above is considered as the heating time t1.

FIG. 6 shows one example of the map prepared in the preliminary test described above and shows a case when the ingot W is heated from 40° C. to 560° C. Here, the horizontal axis represents the weight of the ingot (in unit of gram) and the vertical axis represents the heating time (in unit of second).

FIG. 7 shows a flow chart in heating the ingot and reserving the temperature thereof in the actual furnace, wherein S10 through S20 denote each step in the sequential operation. It is noted that reference is made to FIGS. 3 and 4, as necessary.

To heat the ingot and to reserve the temperature thereof in the actual furnace, the ingot heating starting switch 61 is turned ON at first, the feeding command signal 57a is output from the relay switching circuit 57 based on the heating starting command signal 58c from the heating starting command circuit 58 and the relay 55 is driven to connect the programmed temperature regulator 52 to the heating power control means 62 in Step S10.

Receiving the heating starting command signal 58a from the heating starting command circuit 58, the programmed temperature regulator 52 outputs the measured temperature signal 52a which corresponds to the temperature of the ingot W measured by the radiation thermometer 49 to the analog memory 54 and outputs the heating power control signal 52b to feed power to the induction heating coil 42 and to start to heat the ingot W in Step S11.

At the same time, the programmed temperature regulator 52 starts to time by the timer, compares a time of the timer with the heating time t1 found out from the map. When the time reaches to the heating time in Step S12, it outputs the temperature-up time elapse signal 52c to the analog memory 54 as a measured output fixing command signal and stores the measured temperature signal 52a in the analog memory 54 as a measured value T1 (target temperature) in Step S13.

This stored measured temperature signal 52a is input to the externally inputting temperature regulator 53 as the measurement signal 54a in Step S14.

The temperature-up time elapse signal 52c is input simultaneously to the externally inputting temperature regulator 53 and the temperature set value switching signal input circuit 56 and the relay 55 is driven via the relay switching circuit 57 to connect the externally inputting temperature regulator 53 to the heating power control means 62 in Step S15.

The externally inputting temperature regulator 53 outputs the heating power control signal 53a to the heating power control means 62 to feed power to the induction heating coil 42 to start to reserve the temperature of the ingot W targeting at the temperature of the above-mentioned measured value T1 in Step S16.

At the same time when the heating starting command signal 58d is input to the heat reserving time control circuit 59, the timer in the heat reserving time control circuit 59 starts to time. After a predetermined time set in advance (Step S17) and when the ingot W is replaced in Step S18, the weight of the ingot W is measured in Step S19. If the weight of the ingot W is the same with that of the previous ingot W, the process returns to the beginning of the flow chart. If it is different at step S20, the process returns to Step S2 to repeat the same process.

When no ingot W is replaced, the stop command signal 59a is output to end the heating (heat reservation) of the ingot, i.e., to stop the machine.

That is, the present invention allows the temperature to be increased in the actual furnace up to the set temperature accurately, similarly to the case when the thermocouple is used, and the temperature to be maintained so that it allows the dispersion of the temperature during heating and heat reservation to be reduced and the quality of metal molding to be improved. Further, because it requires no work of removing the thermocouple or the like, the heating and heat reservation may be carried out in a consecutive process, thus improving the productivity of the metal molding.

Next, a system for heating the metal ingot will be explained.

In FIG. 8, a die 4 is connected to one end of the screw type injector 3. The metal ingot heating machine comprises a vacuum pump 5, i.e., evacuating means, for evacuating the heating chamber 12, an inert gas cylinder 6, an oxygen sensor 7 and a control circuit 80.

The ingot supplied to the heating chamber 12 from the ingot introducing chamber 11, while being controlled sequentially by the control circuit 80, is heated into a semi-molten state. The semi-molten ingot W is transported down to the heat reserving chamber 13, is crushed by the choppers 21 and is injected via the chopping chamber 15 into a cavity 16 of the die 4 directly or indirectly by the screw 2.

A galvanic cell type oxygen sensor whose structure is simple for example is used for the oxygen sensor 7. A current generated by the oxygen sensor 7 is taken out by converting it into a voltage by a load resistor or by a current amplifier to detect an oxygen concentration having a relationship proportional to the sensor output.

FIG. 9 is a block diagram of the inventive metal ingot heating system.

The vacuum pump 5 is connected with the heating chamber 12 via a change-over valve 81 and air within the heating chamber 12 is evacuated when the vacuum pump 5 is driven. A degree of vacuum of the heating chamber 12 is detected by a vacuum guage 82 provided between the vacuum pump 5 and the switching valve 81.

The inert gas cylinder 6 is connected with the heating chamber 12 via a change-over valve 83 to flow an inert gas to the heating chamber 12 while regulating a filling pressure by a pressure control valve 84 provided between the inert gas cylinder 6 and the change-over valve 83. The filling pressure is detected by a pressure guage 85 provided between the heating chamber 12 and the change-over valve 83.

The oxygen sensor 7 is connected with the heating chamber 12 via a change-over valve 86 and detects an oxygen concentration within an atmosphere discharged to the outside passing through a flow meter 87 interposed between the oxygen sensor 7 and the change-over valve 86. A filter 88 is interposed between the heating chamber 12 and the change-over valve 86.

A switch 89 is interposed between a power circuit 90 and the induction heating coil 42 to supply current to the induction heating coil 42 to heat the ingot W.

The control circuit 80 is connected with the vacuum pump 5, the change-over valves 81, 83 and 86 and the switch 89 to switch them in accordance to a preset sequence. The control circuit 80 is connected also with the vacuum guage 82, the pressure guage 85, the flow meter 87 and the oxygen sensor 7 to determine a degree of vacuum, pressure, flow amount and oxygen concentration at each sequential operation.

The sequential operation of the metal ingot heating system constructed as described above will be explained below with reference to FIGS. 9 and 10.

The change-over valves 81, 83 and 86 are closed and the switch 89 is turned OFF in the initial setting in heating the metal ingot.

In a state when the ingot W is sealed in the heating chamber 12, the control circuit 80 outputs a pump operating command signal 80*a* to the vacuum pump 5 at first to operate the vacuum pump 5 and to start the evacuation of the heating chamber 12 in Step S31.

The control circuit 80 outputs a valve On signal 80*b* to the change-over valve 81 to open the change-over valve 81 to be ready for the evacuation of the heating chamber 12 in Step S32. At this time, the control circuit 80 monitors a vacuum confirming signal 82*a* indicating the degree of vacuum from the vacuum guage 82 to confirm the degree of vacuum within the heating chamber 12 with it in Step S33.

Receiving the vacuum confirming signal 82*a* in H level indicating that the degree of vacuum has reached to a predetermined value, e.g., $10^{-2}$torr, the control circuit 80 outputs a valve Off signal 80*c* to the change-over valve 81 to close the change-over valve 81 to hold the vacuum state of the heating chamber 12 in Step S34.

Next, the control circuit 80 outputs a valve On signal 80*d* to the change-over valve 83 to cause the heating chamber 12 to communicate with the inert gas cylinder 6 and to flow the inert gas to the heating chamber 12 while regulating the filling pressure by the pressure regulating valve 84 in Step S35. Because the heating chamber 12 has been evacuated by the evacuation in Step S34 at this time, the inert gas is flowed into the heating chamber 12 quickly.

A gas pressure within the heating chamber 12 is monitored by the control circuit 80 based on a gas pressure confirming signal 85*a* from the pressure gage 85 (Step S36) and when the gas pressure confirming signal 85*a* in H level indicating that the pressure within the heating chamber 12 has reached to a certain pressure, e.g., an atmospheric pressure, is input to the control circuit 80, the control circuit 80 outputs a value On receiving signal 80*e* the change-over valve 86 in Step S37. Then, the control circuit 80 receives a flow amount confirming signal 87*a* from the flow meter 87 to confirm whether or not an amount of the flowing out inert gas atmosphere has reached a predetermined flow amount in Step S38.

When the amount of the inert gas atmosphere has reached the predetermined amount, the control circuit 80 determines whether the oxygen concentration is less than a predetermined value or not based on an oxygen confirming signal 7*a* output from the oxygen sensor 7 in Step S39 and when the oxygen concentration within the heating chamber 12 is less than the predetermined value, e.g., less than 10 ppm, control circuit 80 determines that the oxygen concentration is what is allowable to heat by the induction heating coil 42. If the oxygen concentration is more than the predetermined value, the Step S39 is continued.

When the oxygen concentration is determined to be less than the predetermined value in Step S39, the control circuit 80 outputs a heating requesting signal 80*f* to the switch 89 to close the switch 89 and to heat the induction heating coil 42 in Step S40, thus completing the series of sequences.

It is noted that the signal of the oxygen sensor may be used arbitrarily, not only as the condition for starting heating but also as a condition of an alarm signal in the middle of heating.

As described above, the inventive metal ingot heating system is equipped with the oxygen sensor for detecting an oxygen concentration within an atmosphere of the heating chamber and the control circuit detects the oxygen concentration within the atmosphere of the heating chamber by the oxygen sensor after flowing the inert gas to the heating chamber and before heating the metal ingot, so that the oxygen concentration may be monitored before heating. Accordingly, it allows metal ingots to be heated under an adequate oxygen concentration and good moldings containing no oxide products to be obtained by suppressing the production of the oxide product.

Further, because heating of the heating chamber is started only when the oxygen concentration within the atmosphere of the heating chamber detected by the oxygen sensor is less than the predetermined value according to the present invention, it becomes possible to safely mold even a metal such as a magnesium alloy or an aluminum alloy which burns violently when the oxygen concentration is high and is advantageous in controlling the quality of products.

While preferred embodiments have been described, variations thereto will occur to those skilled in the art within the scope of the present inventive concepts which are delineated by the following claims.

What is claimed is:

1. A method for heating an ingot for injection molding by heating the ingot while measuring a temperature thereof by a radiation thermometer,

said method comprising the steps of:

placing the ingot in a test furnace which is a same type of furnace as an actual furnace, and using a thermocouple as a first means for measuring a temperature of the ingot, and heating the ingot for a heating time t1 that ends when a measured value of said thermocouple reaches a set value;

placing said ingot in said actual furnace which is equipped with a radiation thermometer as a second means for measuring a temperature of the ingot, and heating the ingot to obtain a measured value T1 of said radiation thermometer when the ingot has been heated for a time

equal to the heating time t1; and continuing heating of said ingot by targeting the temperature T1 of said radiation thermometer as a temperature to be controlled, wherein the ingot is crushed to feed to a screw of an injection molding machine.

2. A method for heating the ingot for injection molding, according to claim 1, wherein said set value is determined based on a map prepared in advance showing a relationship between a weight of the ingot and the heating time.

* * * * *

# United States Patent [19]

**Mak**

[11] **Patent Number: 4,919,950**

[45] **Date f Patent: Apr. 24, 1990**


[54] **COMPUTER CONTROLLED, FULLY AUT MATIC, SHORT-ORDER WOK COOKING SYSTEM FOR PREPARING STIR-FRIED CHINESE FOOD**


[75] Inventor: Stephen M. Mak, Los Angeles, Calif.

[73] Assignee: Larry B. Harvey, Los Angeles, Calif.



[21] Appl. No.: 224,740

[22] Filed: Jul. 27, 1988

[51] Int. Cl.[5] .......................... A23L 1/01; A47J 27/00

[52] U.S. Cl. .......................... 426/233; 99/348; 99/357; 99/443 R; 99/486; 426/523

[58] Field of Search .......................... 426/231, 233, 523; 99/326, 348, 357, 443 R, 486; 134/76, 115


[56] **References Cited**

**U.S. PATENT DOCUMENTS**


3,859,644 1/1975 Main .......................... 426/233

4,700,617 10/1987 Lee et al. .......................... 99/348

4,748,902 6/1988 Maurantonio .......................... 99/357



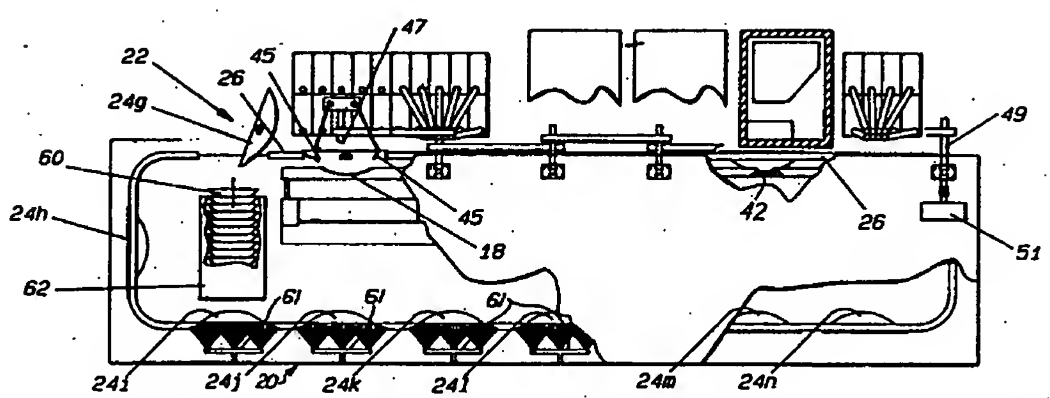
*Primary Examiner*—George Yeung

*Attorney, Agent, or Firm*—Beehler & Pavitt


[57] **ABSTRACT**


A computer controlled, fully automatic wok cooking system prepares stir-fried, Chinese dishes according to arbitrarily selected customer orders entered at a point-of-sale computer. The computer integrates the operation of the conveyer, cooking, dispensing, and point of sale entry devices according the order, menu and ingredients, A conveyor belt including a plurality of woks draws the woks through a plurality of cooking stations. Each station is provided with a burner or heating element and a dispensing station controlled by the computer according to the customer enterd order. Oil or condiments are added at a first station by a corresponding plurality of dispensers and at subsequent cooking stations the food ingredients are either stirred or additional spices, food ingredients and condiments added by corresponding dispensers. At the last cooking station, additional food ingredients, such a vegetables, nuts or other ingredients requiring shorter cooking times, are added and cooking is completed. The completed short order stir-fried dish is then delivered to a serving container at a delivery station. The emptied wok is advanced by the conveyor system through a plurality of cleaning stations, where the wok is inverted, washed, scoured, rinsed and dried. The cleaned and dried wok is then returned by the conveyor system to the initial cooking station to begin the cooking process again according to the then appropriate customer order.


**18 Claims, 6 Drawing Sheets**



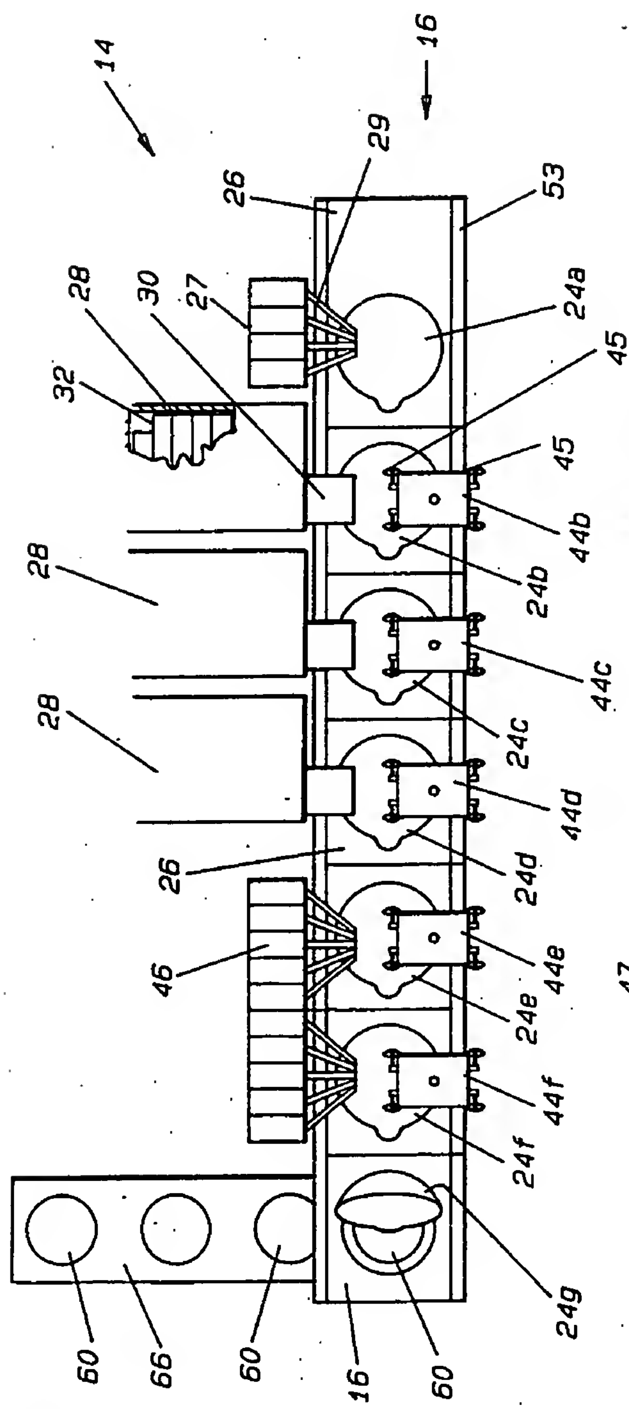

14
16
29
26
53
28
30
27
24a
32
45
45
44b
24b
28
44c
24c
28
44d
24d
26
46
44e
24e
44f
24f
24g
60
66
60
16
60

FIG. 1

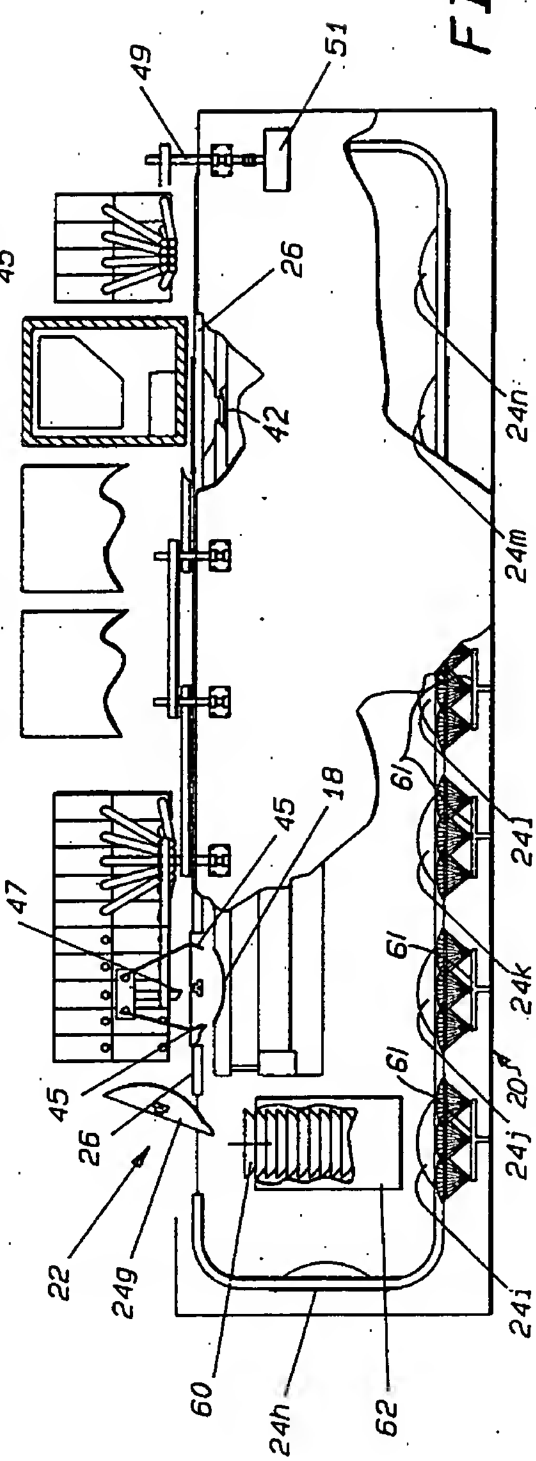

49
51
26
42
24n
24m
45
18
47
6l
24l
6l
24k
45
20
6l
24j
26
22
24g
60
24h
62
24i

FIG. 2

FIG. 3

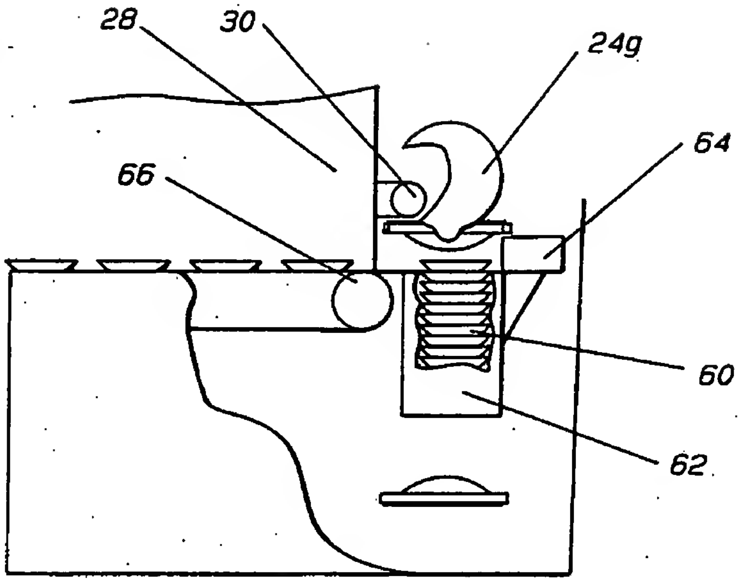



FIG. 4a

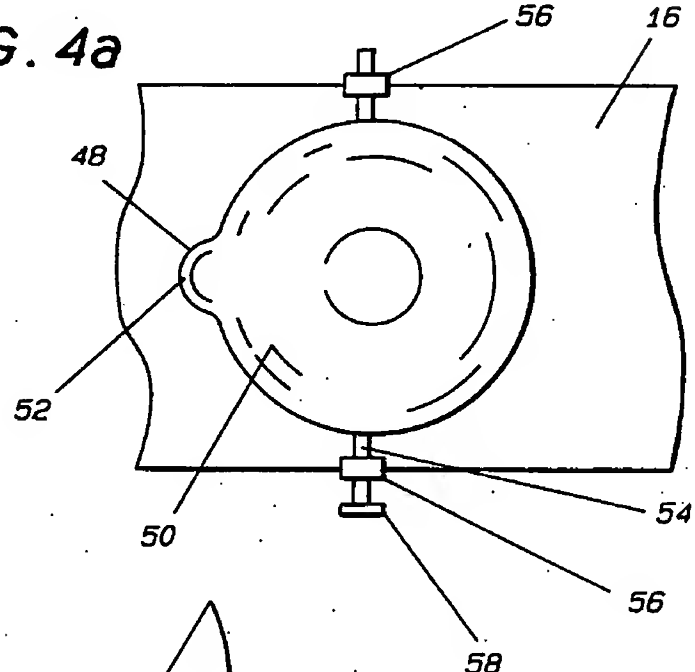
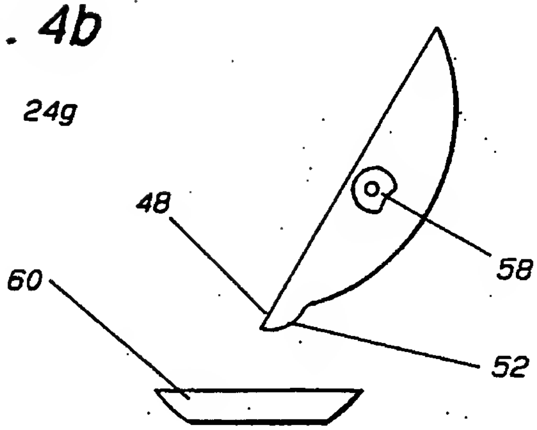
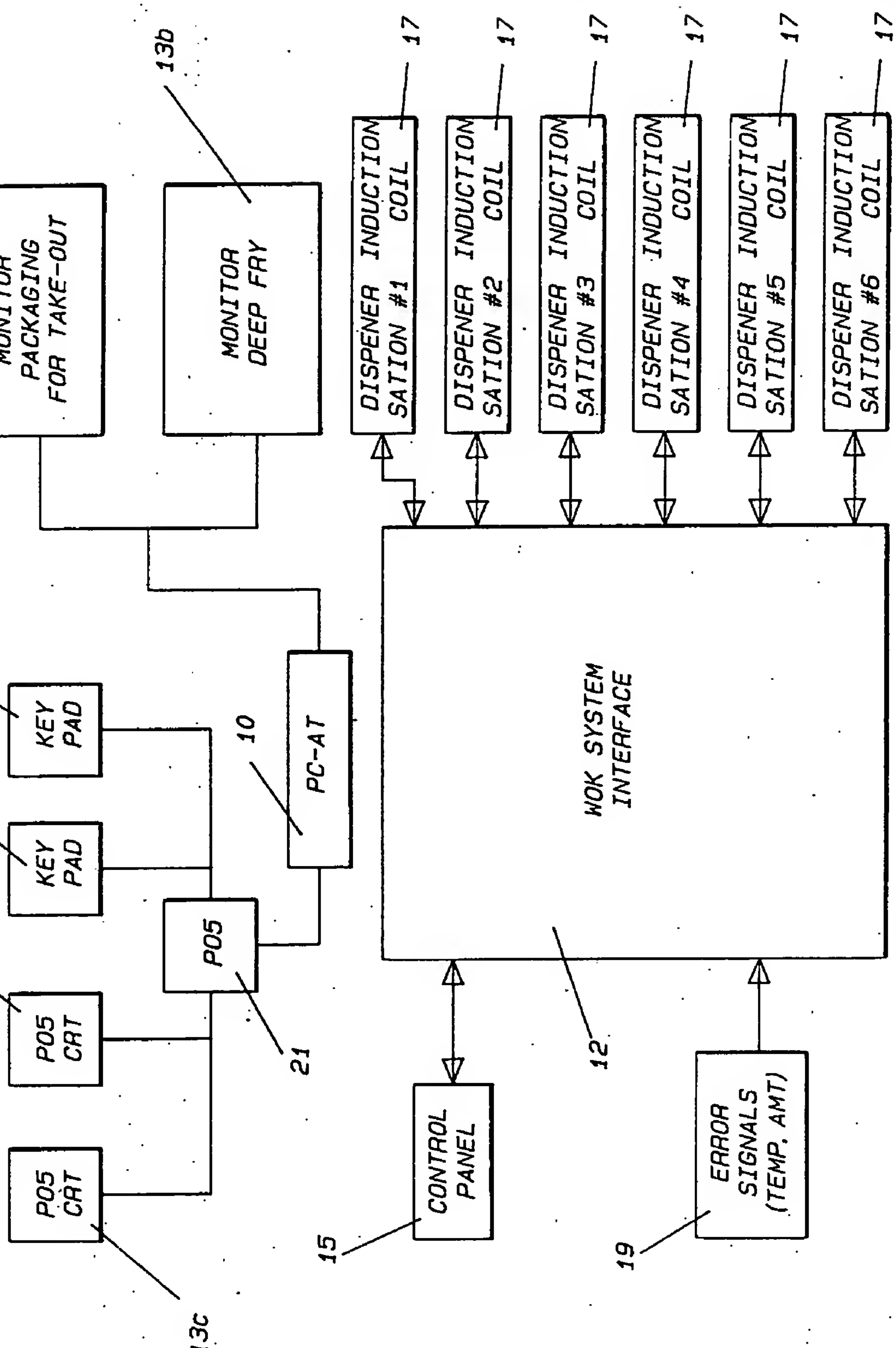



FIG. 4b





MONITOR PACKAGING FOR TAKE-OUT
13a
MONITOR DEEP FRY
13b
DISPENER SATION #1 INDUCTION COIL
DISPENER SATION #2 INDUCTION COIL
DISPENER SATION #3 INDUCTION COIL
DISPENER SATION #4 INDUCTION COIL
DISPENER SATION #5 INDUCTION COIL
DISPENER SATION #6 INDUCTION COIL
17
KEY PAD
11
KEY PAD
11
PC-AT
10
WOK SYSTEM INTERFACE
12
PO5
21
PO5 CRT
13c
PO5 CRT
13c
CONTROL PANEL
15
ERROR SIGNALS (TEMP, AMT)
19


FIG. 5

FIG. 6

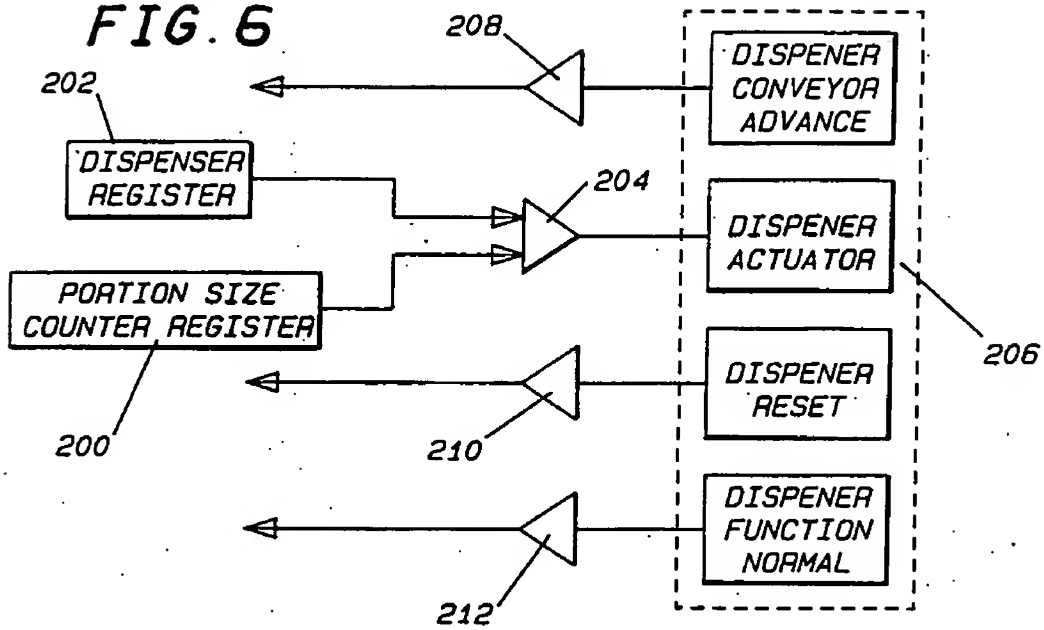
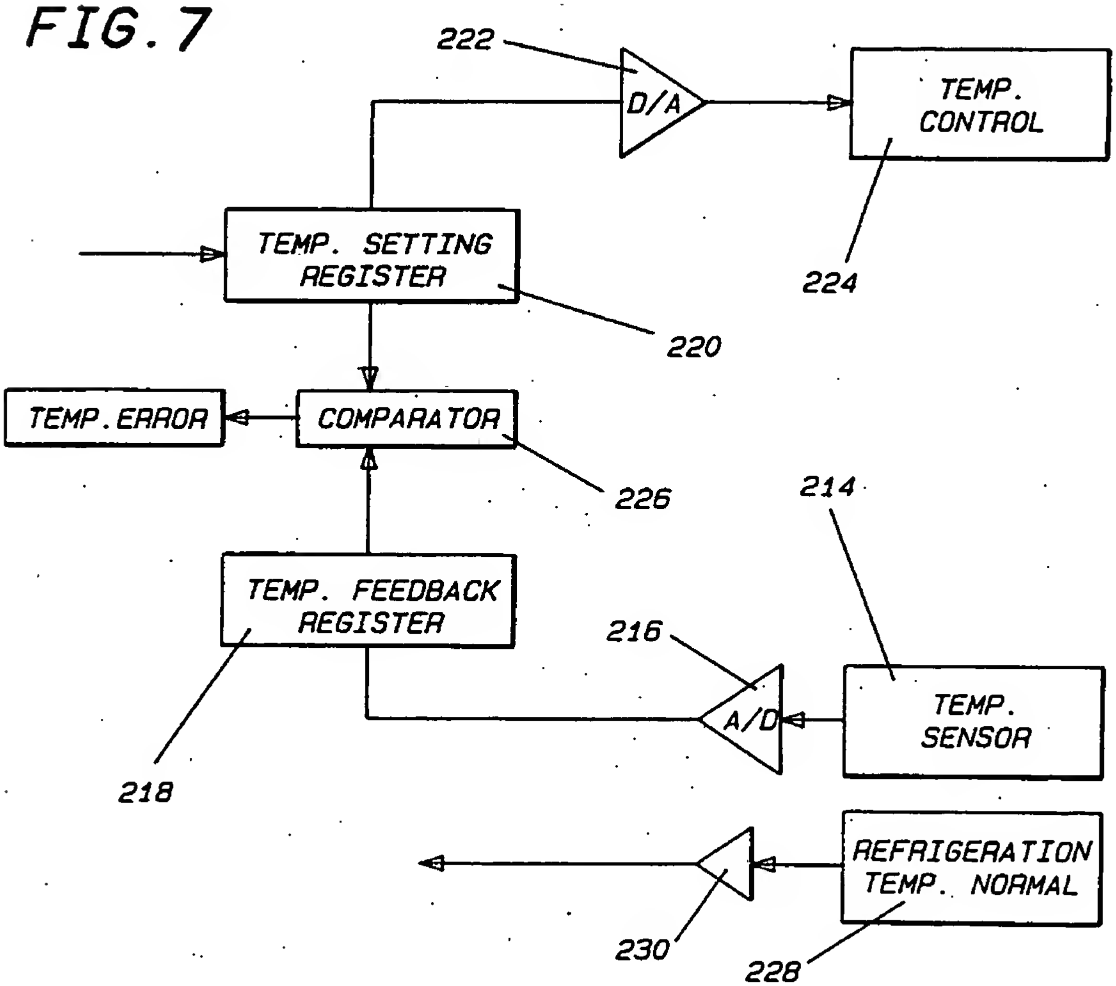
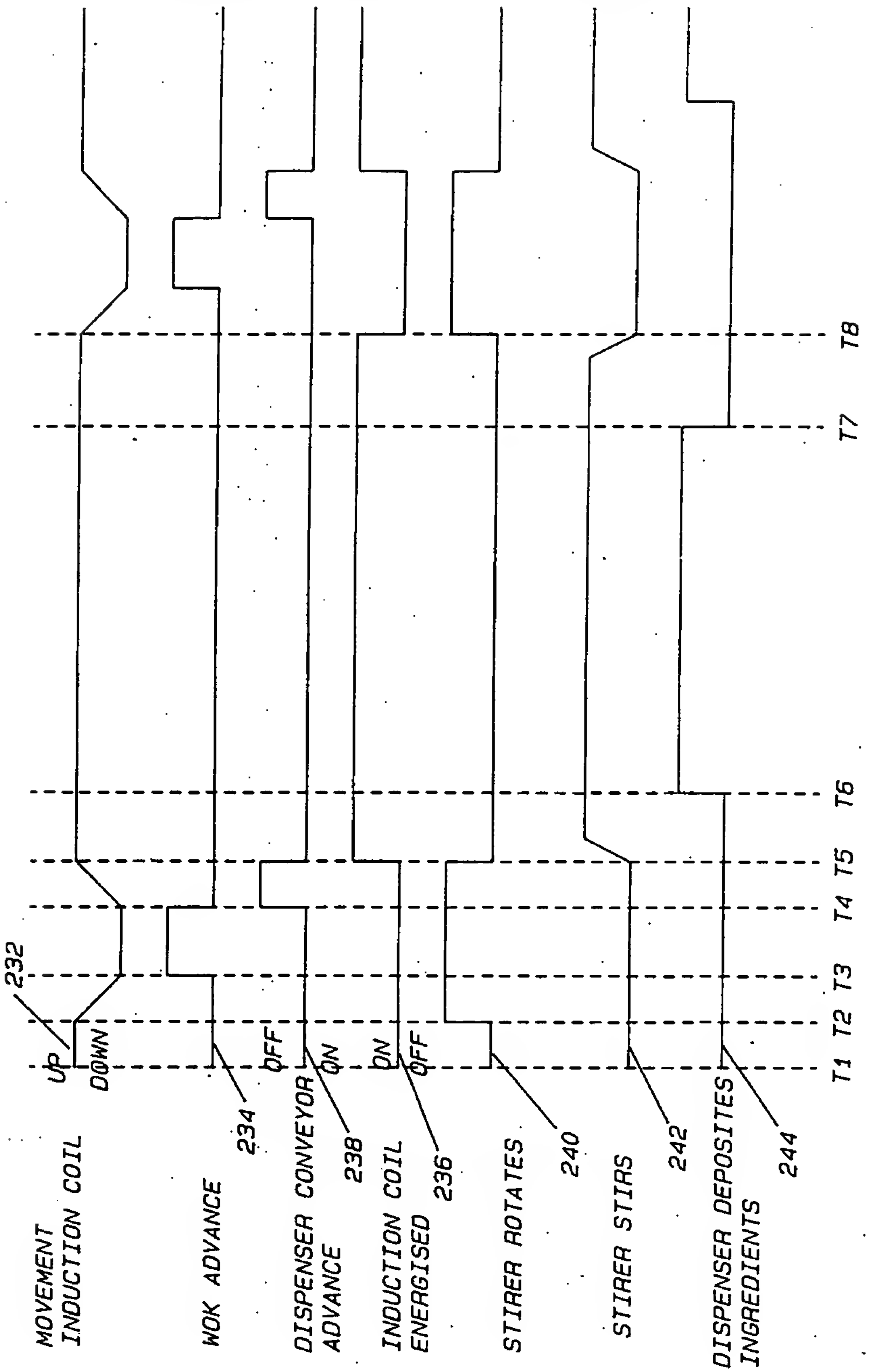

208
202
DISPENSER CONVEYOR ADVANCE
DISPENSER REGISTER
204
DISPENSER ACTUATOR
PORTION SIZE COUNTER REGISTER
206
DISPENSER RESET
200
210
DISPENSER FUNCTION NORMAL
212

FIG. 7


222
D/A
TEMP. CONTROL
TEMP. SETTING REGISTER
224
220
TEMP. ERROR
COMPARATOR
226
214
TEMP. FEEDBACK REGISTER
216
A/D
TEMP. SENSOR
218
REFRIGERATION TEMP. NORMAL
230
228



MOVEMENT INDUCTION COIL
UP
DOWN
232
WOK ADVANCE
234
DISPENSER CONVEYOR ADVANCE
OFF
ON
238
INDUCTION COIL ENERGISED
ON
OFF
236
STIRER ROTATES
240
STIRER STIRS
242
DISPENSER DEPOSITES INGREDIENTS
244
T1
T2
T3
T4
T5
T6
T7
T8


FIG. 8

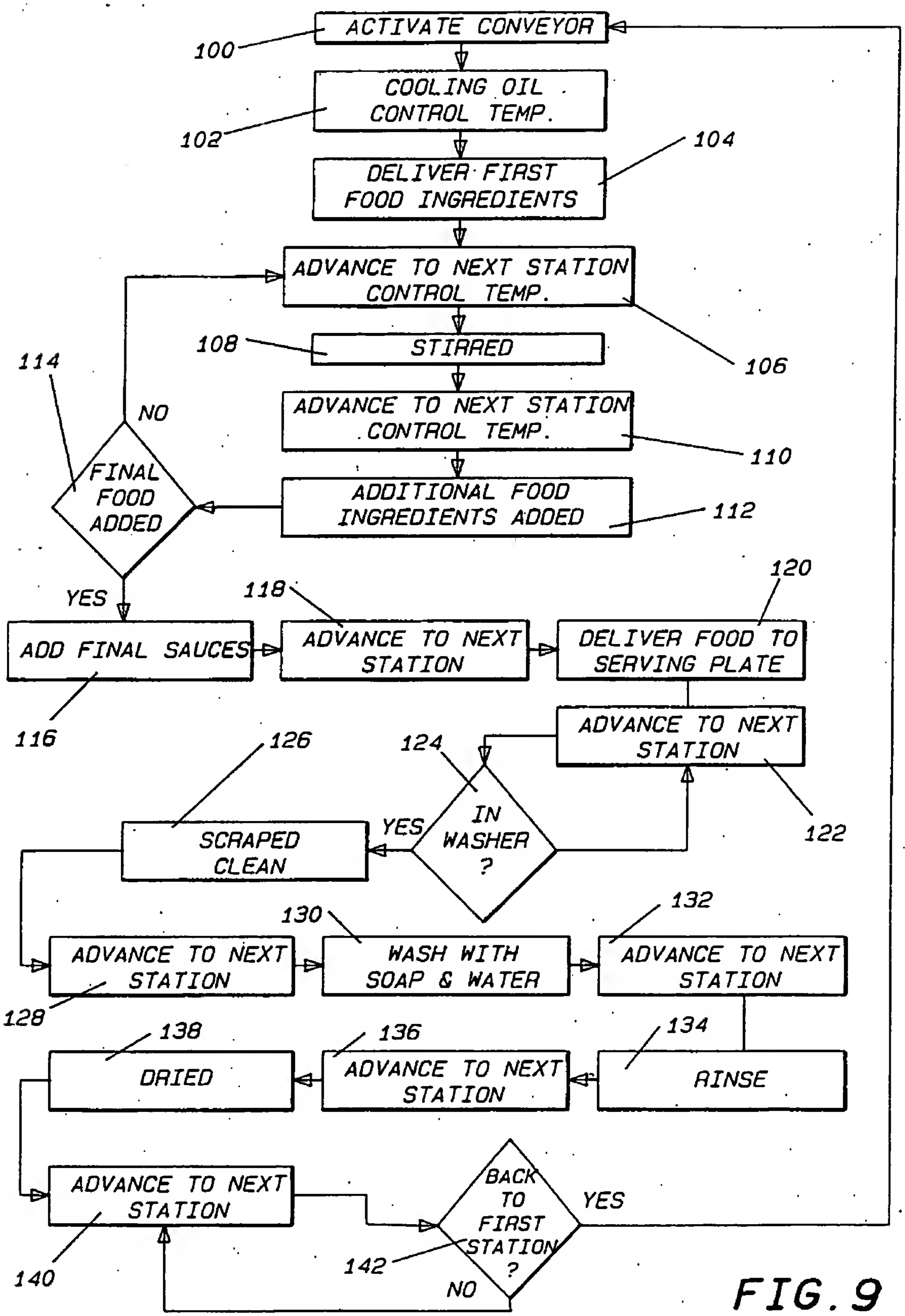

ACTIVATE CONVEYOR
100
COOLING OIL CONTROL TEMP.
102
DELIVER FIRST FOOD INGREDIENTS
104
ADVANCE TO NEXT STATION CONTROL TEMP.
106
STIRRED
108
ADVANCE TO NEXT STATION CONTROL TEMP.
110
ADDITIONAL FOOD INGREDIENTS ADDED
112
FINAL FOOD ADDED
114
NO
YES
ADD FINAL SAUCES
116
ADVANCE TO NEXT STATION
118
DELIVER FOOD TO SERVING PLATE
120
ADVANCE TO NEXT STATION
122
IN WASHER ?
124
YES
SCRAPED CLEAN
126
ADVANCE TO NEXT STATION
128
WASH WITH SOAP & WATER
130
ADVANCE TO NEXT STATION
132
RINSE
134
ADVANCE TO NEXT STATION
136
DRIED
138
ADVANCE TO NEXT STATION
140
BACK TO FIRST STATION ?
142
YES
NO

FIG. 9

## COMPUTER CONTROLLED, FULLY AUTOMATIC, SHORT-ORDER WOK COOKING SYSTEM FOR PREPARING STIR-FRIED CHINESE FOOD

### BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the field of automated restaurant cooking methods and apparatus, and in particular to a conveyor-belt, computer controlled system for providing short order stir-fried meals.

2. Description of the Prior Art

Automatic food processing equipment which utilizes conveyor systems are well known. Typically, such mass production food-processing equipment is used for producing a single type of food item. See, for example, BORSUK, "Method and Apparatus for Continuously Cooking Loaf Meat", U.S. Pat. No. 4,801,564 (1978); LATHAM et al., "Omelet Preparing Machine and Process", U.S. Pat. No. 3,782,169 (1974); LEE, "Fortune Cookie Machine", U.S. Pat. No. 4,339,993 (2982); DIENER et al., "Automatic Food Cooking Machine", U.S. Pat. No. 4,548,130 (1985); KANAGI, "Apparatus for Automatically Cooking Products Made of Batter, Such as Pancakes", U.S. Pat. No. 4,583,451 (1986); SUGIMURA, "Process for Continuous Rice Cooking by Steaming and Apparatus Therefor", U.S. Pat. No. 4,571,342 (1986); and ZEITLIN, "Automatic Turnover Machines", U.S. Pat. No. 2,855,867 (1958).

Even in automated conveyor food-processing systems which utilize computer control, the computer controlled mechanism is utilized for process monitoring of the manufacture of a single type of foodstuff. See, for example BULLERCOLTHURST, "Multi-Conveyor Processing System", U.S. Pat. No. 4,610,886 (1986) and U.S. Pat. No. 4,644,857 (1987).

Prior art devices which are capable of delivering several different types of food do so only in connection with minimal processing of an otherwise completely prepared, instant-food item, such as by adding hot water to a dehydrated food package, as shown in HARASHIMA, "Food Vending Machine with Cooking Apparatus", U.S. Pat. No. 4,030,632 (1977); and RUBINO, "Vending Machine with Fast Cooking Means", U.S. Pat. No. 3,534,676 (1970).

Such apparatus and methods, which provide for mass production of food items allowing some control or variation of the foodstuff, is largely limited to adding mixtures of flavor enhancers to a single type of foodstuff such as shown by BUCKHOLZ et al., "Mixed Seasoning", U.S. Pat. No. 4,514,094 (1985) or allows for some type of a customized cooking operation of a standardized foodstuff without any ability to substantially change or arbitrarily compose the recipe such as shown in RULLMAN, "Apparatus for Processing Food", U.S. Pat. No. 3,702,583 (1972) or BARTFIELD, "Apparatus for Dispensing Individual Orders of a Hot Food Product and Components Usable Therewith", U.S. Pat. No. 4,438,683 (1984).

What each of these prior art devices fails to show, either alone or in combination, is a methodology which can be performed in an automated food processing or cooking system for the control of a multiplicity of arbitrarily chosen, individualized cooking operations, such as temperatures, cooking times, stirring, addition of ingredients and the like on a dish-by-dish basis according to arbitrary customer order selection or short order.

Therefore, what is needed is a methodology and apparatus which can provide for automated fast food cooking of arbitrarily selected short orders.

### BRIEF SUMMARY OF THE INVENTION

The invention is an apparatus for fully automatic cooking of short order meals comprising a plurality of cooking containers, and a conveyor for advancing the plurality of cooking containers along a predetermined path. A heating mechanism or burner heats the plurality of cooking containers as the cooking containers are advanced along the predetermined path by the conveyor. A food dispensing mechanism selectively dispenses a selected amount of selected food to a selected one of the cooking containers at a selected point on the predetermined path. A stirring mechanism stirs food ingredients within selected ones of the cooking containers at selected points on the predetermined path. A computer control mechanism is coupled to the conveyor, heating mechanism, food dispensing mechanism and stirring mechanism for controlling operation of each of the mechanisms according to an arbitrarily selected customer order which is selectively assigned to each one of the cooking containers as each cooking container is advanced along the predetermined path.

As a result, cooked meals are automatically prepared according to a short order selection entered through the computer control mechanism.

In the preferred embodiment the cooking containers are woks. The food dispensing mechanism comprises spice/condiment dispensing mechanisms for selectively providing at least one spice/condiment among a plurality of spice/condiments and a food ingredient mechanism for selectively providing at least one type of food ingredient.

The computer control mechanism comprises a point-of-sale entry mechanism for entering an arbitrarily selected customer order, and a computer for generating a sequence of timed control signals corresponding to each the arbitrarily selected customer orders. A controller mechanism generates drive signals for the conveyor, heating mechanism, food dispensing mechanism, and stirring mechanism to execute the sequence of timed control signals corresponding to the arbitrarily selected customer order.

The heating mechanism comprises a plurality of separate heating elements. Each element is separately controlled by the computer control mechanism to provide a selected degree of heat for a corresponding selective period of time.

The apparatus further comprises a mechanism for removing the food ingredients from each of the plurality of cooking containers after the corresponding food ingredients have been completely prepared, and a cleaning mechanism for cleaning each of the plurality of cooking containers after the food ingredients have been removed from each corresponding cooking container.

The cleaning mechanism comprises washing mechanism for washing each cooking container with a washing solution. A scouring mechanism scours each cooking container. A rinsing mechanism rinses each cooking container, and a drying mechanism dries each cooking container as the plurality of cooking containers are advanced along the predetermined path.

The invention is also a method for automatically preparing arbitrarily selected, short order meals comprising the steps of disposing food ingredients into a

cooking container according to arbitrary customer selection. The food ingredients are disposed into the cooking container by a food dispensing mechanism controlled by a computer control mechanism into which the customer selection is entered. The selected food ingredients are advanced on a conveyor system through a plurality of subsequent cooking stations. Food ingredients are selectively disposed into the container at preselected ones of the plurality of cooking stations. The food ingredients are then selectively manipulated in the cooking container at selected ones of the cooking stations according to the customer order entry as controlled by the computer controlled mechanism. The heating and timing of the food ingredients within the cooking container are selectively controlled at each of the plurality of cooking stations. The food ingredients within the cooking container are delivered when the ingredients are completely prepared according to the arbitrarily entered customer order.

As a result, short orders originated by customers are prepared in a fully automated method.

The method further comprises performing the steps of selectively advancing the food container, selectively disposing food ingredients therein, selectively manipulating the food ingredients therein, selectively heating the food ingredients therein and delivering the food ingredients in a plurality of cooking containers. Each of the cooking containers is advanced on a conveyor system among the plurality of cooking stations. The steps are simultaneously performed in corresponding order to the position of the cooking container within the plurality of cooking stations according to the significance attached to each cooking station by the customer entered short order.

The method further comprises the steps of cleaning the cooking container and returning the cooking container for reuse for a subsequent customer short order. The method comprises the steps of cleaning the plurality of cooking containers at predetermined stations within the conveyor path and returning each of the cleaned cooking containers in sequence for reuse in a plurality of subsequent customer short order entries.

The invention includes an improvement in an apparatus for automatically cooking a plurality of arbitrarily separately selected short order meals. The apparatus comprises a spice/condiment dispensing mechanism for selectively dispensing one of a plurality of spice/condiments.

The invention and its various embodiments may be better visualized by now turning to the following drawings wherein like elements are referenced by like numerals.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic top plan and partially cutaway view of a conveyor system devised according to the invention.

FIG. 2 is a diagrammatic cutaway side view of the system as shown in FIG. 1.

FIG. 3 is a diagrammatic cutaway end view of the system of FIGS. 1 and 2.

FIG. 4*a* is a highly simplified plan view of a wok in the delivery position of the system of FIGS. 1–3 before it is tilted for food delivery.

FIG. 4*b* is a highly simplified side view of the wok of FIG. 4*a* in the delivery position of the system of FIGS. 1–3 after it is tilted for food delivery.

FIG. 5 is a simplified block diagram of the information and control circuitry utilized in combination with the present invention.

FIG. 6 is a simplified block diagram of the information and control circuitry utilized in the interface unit of FIG. 5 in relation to the food dispensing units.

FIG. 7 is a simplified block diagram of the information and control circuitry utilized in the interface unit of FIG. 5 in relation to the temperature control setting and sensing units in the wok subsystem.

FIG. 8 is a timing diagram depicting the methodology used in the wok subsystem of the illustrated embodiment.

FIG. 9 is a flow diagram depicting the computer controlled methodology of the illustrated embodiment.

The invention and its various embodiments may be better understood by now turning to the following detailed description.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present system is an apparatus and a method for computer controlled, fully automatic, short-order wok cooking which is typically used to prepare stir-fried foods, commonly utilized in oriental or Chinese cuisine.

A computer controlled, fully automatic wok cooking system prepares stir-fried, Chinese dishes according to arbitrarily selected customer orders entered at a point-of-sale computer. The compter integrates the operation of the conveyer, cooking, dispensing, and point of sale entry devices according the order, menu and ingredients. A conveyor belt including a plurality of woks draws the woks through a plurality of cooking stations. Each station is provided with a burner or heating element and a dispensing station controlled by the computer according to the customer entered order. Oil or condiments are added at a first station by a corresponding plurality of dispensers and at subsequent cooking stations the food ingredients are either stirred or additional spices, food ingredients and condiments added by corresponding dispensers. At the last cooking station, additional food ingredients, such a vegetables, nuts or other ingredients requiring shorter cooking times, are added and cooking is completed. The completed short order stir-fried dish is then delivered to a serving container at a delivery station. The emptied wok is advanced by the conveyor system through a plurality of cleaning stations, where the wok is inverted, washed, scoured, rinsed and dried. The cleaned and dried wok is then returned by the conveyor system to the initial cooking station to begin the cooking process again according to the then appropriate customer order.

As best depicted in FIG. 5, the system comprises a point-of-sales computer, generally denoted by reference numeral **10**, which is placed at the customer counter or other appropriate location where the customer's order is taken and logged into computer **10** by keyboards **11** or other equivalent means and displayed in a corresponding CRT displays **13*a*–*c***. CRT display **13*a*** is a monitor which may be viewed from the customer and packaging station reserved in the restaurant for takeout service, while monitor **13*b*** is positioned at a deep fat frying station in the food preparation area. Monitors **13*c*** are viewable by the customer, who can track the preparation of his meal on the monitor or view other advertising and promotional messages thereon. The conveyor system of FIGS. 1–3 prepares automated stir-fried foods, while deep fat fried foods are prepared manually

at a separate station, not shown, in a conventional manner.

The internal architecture and circuitry of computer 10 is conventional, e.g. a IBM PC-AT or compatible, is not further relevant to the invention and is therefore not discussed below except where illustrative.

One of the output devices driven by computer 10 is a interface circuit 12 which receives the digital output signals from computer 10 or other appropriate control signals and converts those signals into appropriate control signals or drive signals coupled to operational devices at each of the stations in the cooking system. Interface 12 is comprised of digital decoders which generate command signals for a plurality of drivers or buffers which in turn provide the control or driving signal to various electrical or electromechanical means within the system as described below. Also included in interface 12 are analog-to-digital converters which receive and provide feedback signals from the system to computer 10 for closed loop control of various parameters of the cooking system such as temperature, dispensed amounts, inventory checking, error signals and the like. Details of portions of the circuitry in interface 12 are shown and described in greater detail in FIGS. 6 and 7. For example, interface 12 is bidirectionally coupled to a control panel 15 which allows for manual pushbutton or switched inputs from the food preparers. Information is bidirectionally communicated to a plurality of station food dispensers, symbolically referenced by numeral 17 in FIG. 5. Interface 12 also communicates bidirectionally with a plurality of wok heating elements, symbolically denoted by reference numeral 19 in FIG. 5. However, before describing the electronic control of the entire system, first consider the conveyor system wherein the cooking operation is performed.

The conveyor cooking system, generally denoted by reference numeral 14 in FIG. 1, further comprises a conveyor belt unit, generally denoted by reference numeral 16, controllable heater units, generally denoted by reference numeral 18, a washing subsystem generally denoted by reference numeral 20, and a delivery counter 22. Conveyor 16 comprises typically twelve to sixteen woks which are connected sequentially on a closed-loop conveyor drive. The woks are bowl- or dish-shaped and each wok 24 is carried on a metallic belt 26 above heaters 18. The length of conveyor belt 16 is divided into a plurality of stations with each station having an operative element positioned at the station. For example, an oil, condiment and spice dispensing unit 27 is provided at a first preheat station as shown in FIG. 1 in connection with wok 24*a*. Dispensing unit 27 may be used to selectively dispense:

vegetable oil in 0.2, 0.4 and 0.6 oz units;
salt in 0.05 oz units;
dried red chilies in 0.1 oz units;
crushed Szechuan peppercorns in 0.05 oz units;
star anise in 0.05 oz units;
minced garlic in 0.1, 0.2, and 0.5 oz units;
minced ginger in 0.1, 0.2, and 0.5 oz units; and
orange peel in 0.8 oz units.

The selection and delivery amounts of ingredients is illustrative only and may be changed as desired. Thus ingredient listings may be arbitrarily modified within the teachings of the invention without departing from its scope.

Wok 24*a* is preheated by a corresponding heater unit 18*a* which heaters in the preferred embodiment are electrical induction heaters capable of directly heating each wok 24 to stir-fry temperatures within a few seconds. A predetermined measurement of oil, condiments and spices is added from a conventional liquid/solid dispensing unit 27 and directed through dispensing tube 29 into wok 24*a* in the first preheat station.

A food or meat ingredient dispenser 28 is provided at a second station at which wok 24*b* is depicted. Dispenser 28 is comprised of a horizontal conveyor belt 30 having a plurality of bins 32 configured in its interior. Each bin is funneled or directed toward belt 30 which terminates or turns above wok 24*b*. Alternatively, many types of solid chunk or liquid delivery dispensers are known to the art and any one of them may be used in conveyor system 14. In the illustrated embodiment, dispenser 28 selectively delivers:

whole egg in 1.8 and 2.5 oz units;
lo mein noodles in 6 and 8 oz units;
nest of noodles in 2.5 oz units;
fried rice base in 8 oz units; or
chicken broth in 0.4 and 8 oz units.

The food listed above, typically prepared, are loaded within horizontal bins 32 for dispensation onto conveyor belt 30. Each bin 32 is provided with a separate movable piston, feed screw, or other motive means (not shown) which is controlled by interface 12 in response to commands from computer 10. Dispenser 28 is a conventional food dispenser capable of delivering predetermined amounts of solid or liquid food elements. In any case, each bin 32 is selectively indexed to produce a quantity of food products. Ultimately a measured amount of the food ingredient is delivered from its respective bin 32 onto belt 30 into waiting wok 24*b* at the second station of the system 14.

Each station, except for the first preheating station shown as occupied by wok 24*a* in the illustrated embodiment, is subject to mechanical stirring by a corresponding stirrer 44*b–f*. In other embodiments the first station may also have a stirrer 44 associated therewith. Each stirrer 44 is centered on station with a rotatable drive shaft 47 as shown in side view in FIG. 2. Shafts 47 are each coupled through a chain of pulleys and belts with adjacent stirring mechanisms 44. Ultimately, the stirrer at the first station, corresponding to wok 24*b* as shown in FIG. 1, is coupled to a drive shaft 49 through a belt and pulley combination. Shaft 49 in turn is driven by a torquer 51 which provides the motive force to turn each of the stirring mechanisms 44 by 180 degrees. For example, as shown in FIG. 1, each stirring mechanism has a first and second pair of stirring tools 45. When the first pair of tools 45 is positioned along the center line and in a wok at the corresponding station, the second pair of stirring tools is positioned on the opposing side of stirring mechanism 44 and are is disposed in a washing trough 53. Washing trough 53, which extends from the side of belt system 16 may be either a trough of running water. Thus, after one pair of stirring tools 45 has been utilized, each stirring mechanism 44 is rotated so that the just-used pair of tools 45 are disposed within washing trough 53. Food particles, spices and other ingredients which may adhere to stirring tools 45 are thus washed from the tool so as to prevent food or flavor mixing or contamination with the next adjacent wok moved into the corresponding station, which next wok could typically be provided with an entirely different constituent recipe and ingredients.

The upper portion of each stirring mechanism includes an electromechanical drive (not shown) which reciprocates stirring tools 45 to simulate the tossing and

mixing action of hand held spatulas. In addition, each stirring mechanism is capable of a predetermined amount of vertical movement along the line of its corresponding shaft 47 so that stirring tools 45 can be lifted out of the interior of the corresponding wok to permit rotation of stirring mechanisms 44 by 180 degrees and then relowered both to lower the new cleansed pair of stirring tools 45 into the corresponding wok and to lower the just-used pair of stirring tools 45 into washing trough 53. The mechanism for vertically lifting the upper portion or head of stirring mechanism 44 to vertically dispose stirring tools 45 into and out of washing trough 53 or into and out of the corresponding wok and to reciprocate spatula tools 45 are conventional and will not be further described.

Each wok, such as wok *24b* for example, is positioned above a heater 42 which is also individually controlled by interface 12. Typically, heater 42 is a conventional electric induction heater with the power to it controlled through an electromechanically driven control element. Power to the induction heaters is varied by appropriate solid state SCRs control, control of duty cycle or other means. Therefore, each wok *24a–g* is provided with a selected degree of heat for a selected period of time according to the type of food product which has been selectively dispensed from the corresponding dispenser into the wok.

After a predetermined amount of initial cooking at the second station, wok *24b* then moves to the third station which is depicted in FIGS. 1–2 as occupied by wok *24c*. Wok *24c* has a corresponding heater (not shown) which is similarly connected to and controlled by interface 12 in response to computer 10. The corresponding dispenser at the third station selectively delivers;

a stir-fry vegetable mix in 2, 4 and 9 oz units;
a mu shu vegetable mix in 2 and 4 oz units;
broccoli flowerettes in 7 and 9 oz units;
1½ inch green onion pieces in 1.5 and 2.5 oz units;
sliced waterchestnuts in 1.5 and 3 oz units;
chinese snow peas in 1.5 and 2 oz units;
straw mushrooms in 3 oz units; or
red bell peppers in 1.5 oz units.

The food ingredients added at the third station continue to cook in a selective manner at the third station and are stirred to insure even cooking. The amount of heat applied to the wok at each station is separately controlled at each station and may vary over time at each station.

The third station is followed by one or more additional stations at which additional condiments, food ingredients or stirring functions may be added or performed. In the illustrated embodiment a fourth, fifth and sixth station are provided as depicted in FIG. 1 corresponding to woks *24d* through *24f* with each with a corresponding dispenser 28, heater 18 and stirring mechanism 44 similar to that described in connection with the second station corresponding to wok *24b*.

For example, at the fourth station the following food ingredients are selectively delivered:

egg whites in 1 oz units;
peas and carrots in 1 and 2 oz units;
cubed chicken in 2, 3, 4, 5, and 8 oz units;
sliced beef in 2, 3, 5, 6, 7, and 8 oz units;
shrimp in 2, 3, 5, 6, and 8 oz units;
BBQ pork strips in 2 and 3 oz units;
shredded chicken in 2 oz units; or
Szechuan meat sauce in 6 oz units.



Following the fourth station is a fifth and sixth station depicted by the position of woks *24e* and *f*. Wok *24e* and *f* are also provided with corresponding heaters *42e* and *f* controlled through interface 12 by computer 10. Similarly, the fifth and sixth stations are each provided with a stirring means *44e* and *f* as previously described. However, the fifth and sixth stations have in addition thereto, a spice, sauce or condiment dispenser 46. These are typically solid paste, granulated or liquid food ingredients and are dispensed in selected controllable amounts by means well known to the art.

For example, at the fifth station the following food ingredients are selectively delivered:

soy sauce in 0.4 oz units;
lo mein/chow mein sauce in 4 and 8 oz units;
mu shu sauce in 0.3 oz units;
kung pao sauce in 3 oz units;
garlic sauce 3 oz units; or
orange beef sauce 12 oz units.

At the sixth station the following food ingredients are selectively delivered:

sesame seed oil (spray) in 0.1 and 0.2 oz units;
cornstarch mix in 0.2, 0.4, 0.8, 1 and 1.5 oz units;
peanuts in 1.5 oz units;
cashews in 1 oz units;
almonds in 1 oz units;
rice vinegar 0.2 oz units;
chopped green onions in 0.4 oz units; or
chili oil (spray) in 0.3 oz units.

The final cooking step is then performed with all of the ingredients and spices being stirred together at the last station in the illustrated embodiment. The conveyor belt 16 again advances forwardly and the prepared meal is delivered from the wok, illustrated in FIGS. 1–3 by wok *24g* which is tipped either by inclination of the conveyor belt or preferrably by a tipping mechanism provided specially to incline wok *24g* with respect to the vertical causing its contents to be delivered to a plate 60 placed at the delivery position at the end of conveyor belt 16.

FIGS. *4a* and *b* illustrate the wok in the final or delivery position assumed by wok *24g* in FIG. 1. As depicted in the top plan view of FIG. *4a*, wok *24g* is shaped to include a spout portion 48 along its forward edge 50 which includes a circumferential lip portion 52 designed as a pour spout at a lower level than the remaining portions of the wok. Wok *24g*, and in fact each of the woks, is coupled to belt 16 by means of a pivot bar 54. Pivot bar 54 in turn is journaled within a pivot block 56 attached to belt 16. When the wok reaches the position of wok *24g* in FIG. 1, a cam member 58 attached to pivot bar 54 reaches a cam or eccentric (not shown) mounted by the side of belt 16 at the selected position to tip wok *24g* as best depicted in side view in FIG. *4b*. The prepared meal within wok *24g* is then displaced and delivered to a waiting dish 60 placed in the delivery position by means of a conventional dish elevator 62 in which a plurality of dishes 60 are stored pending use.

As best seen in the side cutaway view of FIG. 3, a dish advancing mechanism 64 controlled by computer 10 and interface interface 12 then advances dish 60 at the appropriate time, namely after delivery of the food contents of wok *24g*, by moving a plunger or carrier against the side of dish 60, taking it from the top of dish elevator 62 and delivering it to a selectively controlled dish conveyor 66. Dish conveyor 66 then advances the dish with the delivered meal to a serving position

wherein the dish is removed and delivered to the customer.

The prepared meal is now cooked, seasoned and stirred and ready for consumption.

It is included within the scope of the invention an an additional mechanism may be included for removing the contents of wok 24g. Such a mechanism could include a scraper or spatula conformed to fit the shape of wok 24g which would rotate it like a paddle forcing the contents of the wok onto plate 60.

After the wok is emptied, the continued indexing conveyor belt 16 brings the wok to the underside of the conveyor belt as best depicted in FIG. 2. Ultimately, the wok will be inverted and drawn through an automated washing sequence as depicted by the positions of woks 24l–m in FIG. 2. In the first position depicted by wok 24l, the wok is subjected in the inverted position to a spray of hot water and soap ejected from a spraying means 61 onto the interior surface of wok 24l. Thereafter, the wok is moved forward and is subjected to a scraping or cleaning action by scrubber means (not shown) which either directs a powerful blast of air/steam into the inverted inside surface of wok 24j or otherwise provides a mechanical scraper or scouring pad which is utilized to remove any adhering particles of food not dislodged by the spray of the first station.

Thereafter, the woks are further indexed and subjected to a rinsing spray of clean water or steam provided by spraying means (not shown). The washed, scraped and rinsed wok is then advanced to the next station wherein its interior surface is dried by a blast of forced air from a fan (not shown). Water and debris from the washing mechanism is collected in a wash pan and removed through a drain. Steam which is generated by water being evaporated against the heated woks is similarly removed by a conventional exhaust hood and ducted to an outside exhaust port (not shown).

Thereafter, the cleaned and dried woks are returned by the conveyor belt indexing mechanism to the first station as described above to be recycled with the next order.

Consider once again the architecture of the electronic system as depicted in FIG. 5 for the control of the conveyor system 14 depicted in FIGS. 1–4. Each of these six dispenser stations described above includes separately controllable dispensers and heating induction coils, collectively denoted as dispenser station modules 17. The control of these modules is better understood by turning now to the symbolic block diagram of a dispenser station and control module as depicted in FIG. 6 and an error signal module as symbolically depicted in the block diagram of FIG. 7, both of which modules comprise part of interface 12.

In FIG. 6 a register, symbolically denoted by register block 200, contains the portion size or the number of units of a portion of a food ingredient which is to be selectively delivered at the station. Each of the six dispenser stations 17 incorporates at least one station control module as depicted in FIG. 6. The module also includes a dispenser register 202 which is an addressable unit identifying which of the dispenser sub-units within the station are to be selectively activated. None, one, or any number of the dispenser sub-units at a station may be simultaneously activated to deliver the selected number of units of the food ingredient at the station. The numbers stored within dispenser register 202 and portion size counter register 200 are coupled to logic within a device driver 204 which responsively generates an on/off signal to the electromechanical unit that causes the food ingredient to actually be delivered and a signal which controls the length of activation or other means by which the portion of food which is to be delivered is controlled. The output of device driver 204 is thus communicated to the electromagnetic dispensing actuator, symbolically denoted by reference numeral 206 in FIG. 6.

Feedback signals are also generated within the dispensing unit which are communicated back through the dispenser station control module. For example, a signal indicative of advance or indexing of a delivery conveyor within the dispenser is provided through a buffer circuit 208. Similarly, a dispenser reset signal is provided through a buffer 210 and a dispenser function normal signal is provided to buffer 212. By this means the status or condition of the dispenser actuator 206 can be monitored and appropriately timed through interface unit 12 subject to program control. As many dispenser station control modules as depicted in FIG. 6 will be included within each station as there are separately controllable food ingredients to be delivered.

FIG. 7 is a symbolic diagram depicting one embodiment of the error reporting signals within circuit block 19 of FIG. 5. The temperature of the wok as heated by the induction heater at each station is monitored by a temperature sensor 214. The analog output of temperature sensor 214 is then converted by an analog-to-digital converter 216 and stored within a temperature feedback register 218. Meanwhile, the programmably controlled temperature setting for the induction heater at the station has been loaded within a temperature setting register 220. The contents of register 220 are converted in a digital-to-analog converter 222 provided as an analog drive control signal to a temperature control unit 224 within the induction heater at the station. The temperature which is actually achieved is thus sensed by temperature sensor 214 and ultimately presented in digital form in temperature feedback register 218. The contents of temperature setting register 220 and temperature feedback register 218 are then each coupled to a comparator 226. If the degree of difference between the contents of registers 218 and 220 exceeds a predetermined threshold, comparator 226 generates a temperature error signal or alternatively simply transmits the actual temperature difference to interface 12 and thence to computer 10 wherein an appropriate control response is made.

In addition to control of the heating temperature at each station, many dispensers will require refrigeration since the dispensers will contain perishable food ingredients which might be degraded by temperature and time. Therefore, a refrigeration temperature sensor 228 is provided within the refrigerated portion of each dispenser at each station and buffered through buffer 230 for communication to interface 12. Again, the refrigeration temperature is monitored by computer 10 through interface 12 to insure that the perishable food ingredients are kept within predetermined temperatures as required by appropriate health and sanitation considerations. Thus, each one of the six stations as depicted in FIGS. 1 and 2 will incorporate an error signal circuit 19 as described in connection with FIG. 7.

Since the various elements of the conveyor system 14 have now been described in detail, consider the timing diagram of FIG. 8 which illustrates the typical timing of the operation of the units at each station. Curve 232 represents the control signal relating to movement of

the induction coil at each station. The induction heating is effective only when the induction coil is placed in close proximity to the stainless steel wok. Conveyor belt 16 is maintained in a fixed plane so that the induction coils are raised or lowered as depicted in FIG. 8 to couple and decouple the induction coils to the woks and to allow movement of the woks with conveyor belt 16. At time t1 the induction coil is up or in place against at wok and coupling is possible. However, at time t2 the induction coil begins to move downwardly and clears the bottom of the wok by time t3. The induction coil remains in the lowered position until time t4 and then begins again move to the up position. By time t5 the induction coil is once again in the up position and coupling with the adjacent wok is again possible.

Therefore, curve 234 is representative of the wok advance at a station and can be shown as coordinated with the movement of its corresponding induction coil. For example, the woks remained in position until time t3 until the induction coil is all the way down. At the time t3 the wok advances and continues to advance until the time t4. Thereafter, the induction coil is moved up into place and cooking is commenced.

Similarly, movement of stirrers 44 is depicted by curve 236. The stirrer mechanism moves up and begins to rotate as a whole at time t2. At the same time the induction coil begins to be lowered. Rotation of the stirrer continues from time t2 through time t5 so that the stirring mechanism has rotated 180 degrees between times t2 and t5. At time t5 the stirrer is lowered, thereby placing a clean pair of stirring tools into the wok, which has arrived in place by the preceding time t4.

The activation of the dispenser conveyor or other equivalent mechanism is represented by curve 238. The dispensers at the station are quiescent until time t4 after the wok has been completely positioned. At time t4 the food ingredients are dispensed until time t5 at which time the induction coil is now in place as is the stirring mechanism. Thereafter the dispenser conveyor or other feed mechanism is again quiescent. At time t5 the induction coil, which has been turned off, as depicted by curve 240, is turned on. The wok is rapidly heated as described above and the cooking process commences as does the activation of the stirring tools as represented by curve 242. Stirring thus continues until time t8 which is the beginning time interval of the next cycle and which thus corresponds to time t2 of the cycle just described.

Delivery of the ingredients is depicted by the timing curve 244. Information is communicated to the dispenser station control modules for each dispenser at the station as described in connection with FIG. 6 between times t5 and t6. At time t6 the food ingredients are dispensed until time t7 during which period stirring and cooking continue. Delivery of food ingredients is completed on or before time t7 and the cycle terminates at time t8 and the next cycle begins immediately thereafter.

Because the computer control system is in effect an automated system for producing arbitrarily selected short orders and is computer controlled in each of the process steps, a number of striking advantages arise. First of all, inventory of food items within the dispensing units in conveyor system 14 is continuously monitored. Each of the food dispensers will have a fixed amount of food in each food container when full, typically 15–30 pounds of solid food ingredients, a gallon or half gallon of liquid. As food production progresses, computer 10 will through software control relate the ordering data from the point of said entry with the inventory data pertaining to the food within the dispensers. When one of the dispensers has less than a minimum number of servings left, say five servings, an automatic alarm may be generated and sound at control panel 15 shown in FIG. 5. A light will then be illuminated indicating which station and dispenser needs to be refilled. The food preparation attendant can then take remedial action and input the action taken at control panel 15 thereby allowing the inventory to be updated. In a case when any dispenser has run out of food, computer 10 can immediately hold back the order whose recipe calls for the ingredient until either the dispenser is filled or the customer selects a different menu item. Meanwhile, other food orders which are received at the point of sale can be inserted within the control stream without being backlogged or delayed.

Furthermore, with the ability to track real time use of food inventory, actual histories of food usage and selection for any given installation can be tracked and anticipatory purchase orders made to meet the customer demands to insure that adequate supplies of properly prepared food ingredients are pre-prepared and maintained for dispensing.

In addition to coordinating the processing of food dishes in conveyor system 14, non-automated food preparation steps may also be efficiently coordinated. For example, instructions coordinated with meals being prepared within the automated conveyor system 14 are displayed on the package monitor 13*a* or deep fry monitor 13*b* where an attendant can prepare or package the requested food item manually so that it is delivered hot or at the appropriate time and condition for serving with the automatically prepared stir-fried meal. The attendant can remove the order form the package monitor 13*a* or deep fry monitor 13*b* by an appropriate input device to confirm timely compliance with the instructions issued by computer 10 according to the meal menu and coordination with other elements of the meal.

Still further, cash receipt, orders, food usage and usage of nonfood items can all be directly or indirectly monitored through the use of histories developed within computer 10 as entered at the point of sale. This information can be stored for later transmittal or transmitted real time to an off-site computer or output device to provide on-site daily summaries or to provide reporting to a distant management or franchiser office for use in business and quality control. Such communications from computer 10 are inexpensively and easily handled through modems and telephonic links and therefore have not been described in greater detail here.

The operation of the circuit architecture as shown in FIG. 5 can be better visualized by considering the functional relationship of the various elements shown in Table 1 below. The point of sale units which include the monitors 13*a*–13*c* and keypads 11 are similarly microprocessor driven through appropriate firmware stored within a ROM. The ROM and processor within the point of sale units include interface programs, initializing programs, appropriate system diagnostics relating to the operation of the point of sale device and data communication through conventional RS232 ports to computer 10. The leftmost column of Table 1 outlines the point of sale device. 64KB of RAM are included for ordinary point of sale operations such as storing information which would be required for a display driver to communicate with point of sale CRT's 13*c* in FIG. 5, a

keyboard decoder for communication with key pads 11, and recordal of appropriate transactions relating to the cash drawer and menu selection. Included within point of sale unit 21 is a section of buffer storage which provides a historic recall ability of the day's transactions and recall of any order through a customer identification order which is automatically assigned.

Point of sale unit 21 communicates as suggested in Table 1 with computer 10 whose function is outlined in the second column of the table. Computer 10 provides a monitor display program, a data communication program, a transaction program, an interface interrupt program, a customer order file into which the dispensing stations and their corresponding temperature settings are stored for each customer number and/or dish number, as well as a menu/ingredient file which designates the portions and sizes and the selected dispensers which are to be called up for any given order. Also included within computer 10 is a point of sale initializing file which initializes point of sale unit 21. The programs stored and maintained within computer 10 also include on-line test programs for error conditions and overall system diagnostics such as a identification of station and a dispenser error reset codes along with the temperature error and other error conditions which may be warranted. Still further, computer 10 provides a program for monitoring an input keyboard related to the package monitor 13*a* or deep fry monitor 13*b* and point of sale key pads 11. Customer numbers and dish numbers are also tracked and can be communicated through a modem and auto-dial program executed at appropriate times by computer 10. Finally, computer 10 monitors the status of each dispenser for inventory control as described above.

Each of these cooking commands sent to or received by computer 10 are transmitted via a conventional RS232 port as indicated in the fourth column of Table 1 to interface 12 which is outlined by the fifth column in Table 1. Interface 12 is also microprocessor-controlled and includes both firmware memory and RAM memory. Timers, and analog-to-digital, digital-to-analog and actuated drivers and registers as described in connection with FIGS. 6 and 7 are all included within interface 12.

As depicted in the rightmost column in Table 1, interface 12 is then bidirectionally communicated with control panel 15 described above and the dispenser stations wherein electromechanical actuated drivers are controlled, temperature settings and feedbacks are set or sensed, dispenser control functions are reset and monitored, dispenser conveyor functions are advanced, and refrigeration temperatures are monitored as well as DC power. In addition to each of the dispenser stations, each station also includes control signals provides bidirectional communication with the wok mechanism relating to: the position of the induction coil; advancement of the wok; operation of the stirrer; rotation of the stirrer; activation or nonactivation of the serving mechanism to deliver food from the wok into a dish as exemplified by the wok 24*g* in FIG. 1; advancement of the dish from the dish supply; monitoring of the dish supply within the dish elevator 62; and a number of other error signals. Wok related error signals include: a dish conveyor overrun; a scrubber function signal; a soap spray function; a water system function signal; steam dry system function signal; and monitoring of AC and DC power levels. All these conditions are monitored and are communicated through the RS232 port to the interface unit 12 for processing within computer 10 according to appropriate program control.

The general apparatus of the illustrated embodiments now having been described, consider its method of operation wherein each wok may be provided with an individually specified meal in which the ingredients and cooking cycle are individually varied and tracked through program control so that the apparatus of FIGS. 1–7 produces not a single type of prepared meal but a sequence of selected meals from a short order menu in an arbitrary fashion according to how the orders are received at the point-of-sale computer station 10.

Turn now to the flow diagram of FIG. 8 which depicted one type of program control which could be implemented through computer 10. The flow diagram of FIG. 8 depicts the process to which a single meal would be subjected, each of the meals of the wok in the system having such a program performed in relationship to the meal carried within the wok with appropriate timing.

In step 100 conveyor system 16 is activated to bring a new wok up to the first station. Cooking oil or other food ingredient is dispensed in the wok at station 102 while the wok is at the first station. Meanwhile other ingredients are being metered and gathered together as may be appropriate to the order specified by computer 10 and delivered at step 104 to the wok while in the first station. The wok is advanced to the next station at step 106 and the ingredients are stirred at step 108 by providing appropriate command signals to stirring means 44 while the corresponding temperature of heater 42*b* is simultaneously controlled. After a selected time, the wok is advanced to a third station at step 110 and the corresponding temperature at the third station is selectively set if needed. Food ingredients are then added from dispenser 46 at step 112. Again after a preselected time period, the wok is then advanced to the next station for additional stirring at a selected temperature which is indicated in the flow diagram of FIG. 8 as looping back to step 106. The step of stirring such as described in connection with step 108 and advancement at step 110 are then executed together with additional food ingredients at step 112. A determination is then made at step 114 of whether the series of advancements between stirring and adding food ingredients is to continue as exemplified by steps 106–112 or whether the final food ingredient, typically a combination of sauces, is to be added. If the latter is the case, the final sauces are added at step 116 wherein the final food ingredients are added and cooked for a preselected time. The food is then delivered to the serving plate at step 118 and any additional scraping or deliver steps are performed to remove the final prepared meal from the wok to the delivery plate 58. The belt is again advanced to the next station at step 122 until as determined at step 124 it is in the washing station. There it is washed with soap and water at step 126, advanced at step 128 and scraped or scoured clean at step 130. It is advanced at step 132 to the next station and rinsed at step 134, advanced again at step 136 and dried at step 138. It continues to be advanced at step 140 as determined by the decision at step 142 until the specified wok is returned to the first conveyor station and the program reentered at step 100.

Many modifications and alterations may be made by those having ordinary skill in the art without departing from the spirit and scope of the invention. For example, although automated short-order preparation of Chinese stir fried foods has been described, it is expressly con-

templated that other kinds of foods may be prepared according to the teachings of the present invention.

Still further, specific food dispensing and stirring mechanisms have been shown or described, it is entirely within the scope of the invention that other types of dispensers and stirrers now known or later devised could be included. Furthermore, the illustrated embodiments have shown a sequence of food dispensers and stirrers in alternating array. It is entirely within the scope of the invention that this sequence may be arbitrarily altered so that two or more stirrers or food dispensers may be provided one after each other instead of the alternating sequence which has been described. In addition, a plurality of food dispensers or stirring means may be provided for each station or mixed with each other as in the case at the last station as shown in the illustrated embodiment. For example, the vegetable dispensing station may be provided with the last food dispensing station 46 instead of with the last stirring means 44. Furthermore, each of the operable station has been shown as relatively fixed with respect to their respective stirring stations. It is expressly contemplated that the stirrers and dispensers could be moved between stations, either manually from time to time, or could be incorporated in an automated system utilizing movable tracks so that an appropriate stirring means or food dispenser could be brought to the appropriate station by computer control if desired.

Therefore, the illustrated embodiment should be taken as shown only by way of example and clarity and not as limiting the invention which is defined in the following claims.

I claim:

1. An apparatus for fully automatic cooking of short order meals comprising:

a plurality of cooking containers;

a conveyor means for advancing said plurality of cooking containers along a predetermined path;

heating means for heating said plurality of cooking containers as said cooking containers are advanced along said predetermined path by said conveyor means;

food dispensing means for selectively dispensing a selected amount of selected food to a selected one of said cooking containers at a selected point on said predetermined path;

stirring means for stirring food ingredients within selected ones of said cooking containers at selected points on said predetermined path; and

computer control means coupled to said conveyor means, heating means, food dispensing means and stirring means for controlling operation of each of said means according to an arbitrarily selected customer order selectively assigned to each one of said cooking containers as said cooking container is advanced along said predetermined path,

whereby cooked meals are automatically prepared according to a short order selection entered through said computer control means.

2. The apparatus of claim 1 wherein said cooking containers are woks.

3. The apparatus of claim 1 wherein said food dispensing means comprises spice/condiment dispensing means for selectively providing at least one spice/condiment among a plurality of spice/condiments and a food ingredient means for selectively providing at least one type of food ingredient.

4. The apparatus of claim 2 wherein said food dispensing means comprises spice/condiment dispensing means for selectively providing at least one spice/condiment among a plurality of spice/condiments and a food ingredient means for selectively providing at least one type of food ingredient.

5. The apparatus of claim 1 wherein said computer control means comprises a point-of-sale entry means for entering an arbitrarily selected customer order, computer means for generating a sequence of timed control signals corresponding to each said arbitrarily selected customer orders, and interface means for generating drive signals for said conveyor means, heating means, food dispensing means, and stirring means to execute said sequence of timed control signals corresponding to said arbitrarily selected customer order.

6. The apparatus of claim 2 wherein said computer control means comprises a point-of-sale entry means for entering an arbitrarily selected customer order, computer means for generating a sequence of timed control signals corresponding to each said arbitrarily selected customer orders, and interface means for generating drive signals for said conveyor means, heating means, food dispensing means, and stirring means to execute said sequence of timed control signals corresponding to said arbitrarily selected customer order.

7. The apparatus of claim 4 wherein said computer control means comprises a point-of-sale entry means for entering an arbitrarily selected customer order, computer means for generating a sequence of timed control signals corresponding to each said arbitrarily selected customer orders, and interface means for generating drive signals for said conveyor means, heating means, food dispensing means, and stirring means to execute said sequence of timed control signals corresponding to said arbitrarily selected customer order.

8. The apparatus of claim 1 wherein said heating means comprises a plurality of separate heating elements, each element being separately controlled by said computer control means to provide a selected degree of heat for a corresponding selective period of time.

9. The apparatus of claim 7 wherein said heating means comprises a plurality of separate heating elements, each element being separately controlled by said computer control means to provide a selective degree of heat for a corresponding selective period of time.

10. The apparatus of claim 1 further comprising means for removing said food ingredients from each of said plurality of cooking containers after said corresponding food ingredients have been completely prepared to deliver said food ingredients for consumption; and

cleaning means for cleaning each of said plurality of cooking containers after said food ingredients have been removed from each corresponding cooking container.

11. The apparatus of claim 2 further comprising means for removing said food ingredients from each of said plurality of cooking containers after said corresponding food ingredients have been completely prepared to deliver said food ingredients for consumption; and

cleaning means for cleaning each of said plurality of cooking containers after said food ingredients have been removed from each corresponding cooking container.

12. The apparatus of claim 3 further comprising means for removing said food ingredients from each of

said plurality of cooking containers after said corresponding food ingredients have been completely prepared to deliver said food ingredients for consumption; and

cleaning means for cleaning each of said plurality of cooking containers after said food ingredients have been removed from each corresponding cooking container.

13. The apparatus of claim 9 further comprising means for removing said food ingredients from each of said plurality of cooking containers after said corresponding food ingredients have been completely prepared to deliver said food ingredients for consumption; and

cleaning means for cleaning each of said plurality of cooking containers after said food ingredients have been removed from each corresponding cooking container.

14. The apparatus of claim 10 wherein said cleaning means comprises washing means for washing each said cooking container with a washing solution, scouring means for scouring each cooking container, rinsing means for rinsing each cooking container, and drying means for drying each cooking container as said plurality of cooking containers are advanced along said predetermined path.

15. A method for automatically preparing arbitrarily selected, short order meals comprising the steps of:

selectively disposing food ingredients into a cooking container according to arbitrary customer selection, said food ingredients being disposed into said cooking container by a food dispensing means controlled by a computer control means into which said customer selection is entered;

advancing said selected food ingredients in said cooking container on a conveyor system through a plurality of subsequent cooking stations;

selectively disposing additional food ingredients into said container at preselected ones of said plurality of cooking stations;

selectively stirring food ingredients in said cooking container at selected ones of said cooking stations according to said customer order entry as controlled by said computer controlled means;

selectively controlling heating and timing of said food ingredients within said cooking container at each of said plurality of cooking stations; and

removing said food ingredients from said cooking container when said ingredients are completely prepared according to said arbitrarily entered customer order,

whereby short orders originated by customers are prepared in a fully automated method.

16. The method of claim 15 further comprising performing said steps of selectively advancing said food container, selectively disposing food ingredients therein, selectively manipulating said food ingredients therein, selectively heating said food ingredients therein and delivering said food ingredients in a plurality of cooking containers, each of said cooking containers being advanced on a conveyor system among said plurality of cooking stations, said steps being simultaneously performed in corresponding order to the position of said cooking container within said plurality of cooking stations according to the significance attached to each cooking station by said customer entered short order.

17. The method of claim 15 further comprising the steps of cleaning said cooking container and returning said cooking container for reuse for a subsequent customer short order.

18. The method of claim 16 further comprising the steps of cleaning said plurality of cooking containers at predetermined stations within said conveyor path and returning each of said cleaned cooking containers in sequence for reuse in a plurality of subsequent customer short order entries.

* * * * *

US-PAT-NO: 5033720

DOCUMENT-IDENTIFIER: US 5033720 A

TITLE: Apparatus for determining metal properties

---------- KWIC ---------

Detailed Description Text - DETX (2):

In FIG. 1 a flow chart of the steps of measurements that can be conducted by the apparatus of this invention in which numeral 10 indicates a step of mounting a metal specimen on a measuring device; numeral 11 indicates a step of connecting a **temperature** measuring device, such as a thermal couple, to the metal specimen; numeral 12 indicates a step of predetermining a **temperature** variation pattern of the specimen by a programmable **temperature** controller; numeral 13 indicates a step of treating the metal specimen under the control of the **temperature** controller; numeral 14 indicates a step of measuring the in-situ internal friction behavior, expansion curve and/or magnetic property variation curve of the metal specimen; and numeral 18 indicates a step of **recording** the measured data so as to provide a better understanding of metals.
In the heating step 12, the metal specimen may be heated by several different treatments such as annealing, tempering or quenching. No matter what kind of heat treatment is used, the metal specimen is kept

# United States Patent [19]

**Chen**

[11] **Patent Number: 5,033,720**

[45] **Dat of Pat nt: Jul. 23, 1991**


[54] **APPARATUS FOR DETERMINING METAL PROPERTIES**


[75] Inventor: Hong-Bin Chen, Kaohsiung, Taiwan

[73] Assignee: China Steel Corporation, Taiwan



[21] Appl. No.: 499,198

[22] Filed: Mar. 23, 1990

**Related U.S. Application Data**

[63] Continuation of Ser. No. 212,520, Jun. 28, 1988, abandoned.

[51] Int. Cl.[5] .............. C21B 7/24

[52] U.S. Cl. .............. 266/79; 266/80; 266/99

[58] Field of Search .............. 148/128, 129; 266/88, 266/79, 80, 99, 78



[56] **References Cited**

U.S. PATENT DOCUMENTS

| | | | |
|---|---|---|---|
| 4,407,682 | 10/1983 | Sawa et al. | 148/128 |
| 4,595,427 | 6/1986 | Drew et al. | 266/78 |
| 4,648,916 | 3/1987 | Morita et al. | 148/128 |

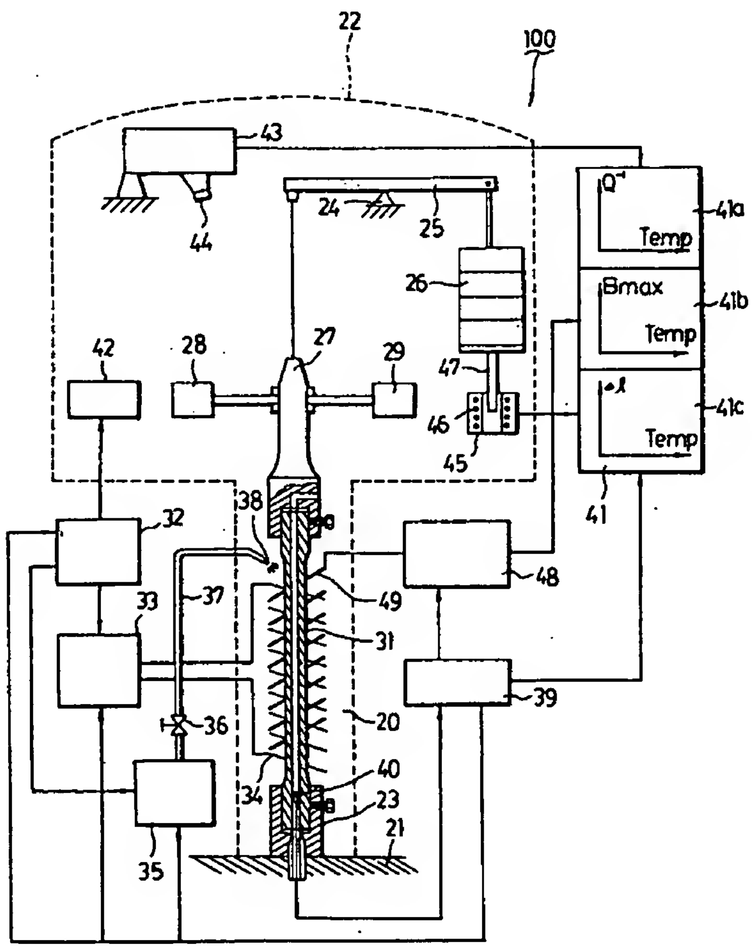


*Primary Examiner*—S. Kastler
*Attorney, Agent, or Firm*—Ladas & Parry


[57] **ABSTRACT**


A torsion pendulum apparatus and a dialometer are combined for simultaneous measurement of the internal friction and the expansion of an alloy. The combination is controlled by a programmable controller so as to conduct in-situ measurements of the internal friction and the expansion of a metal during its phase transformation or specific heat treatment. The results of the internal friction measurement and the expansion measurement can be checked and assumed by one another so that more accurate and detailed information can be obtained for the study of metal alloys.


**2 Claims, 3 Drawing Sheets**



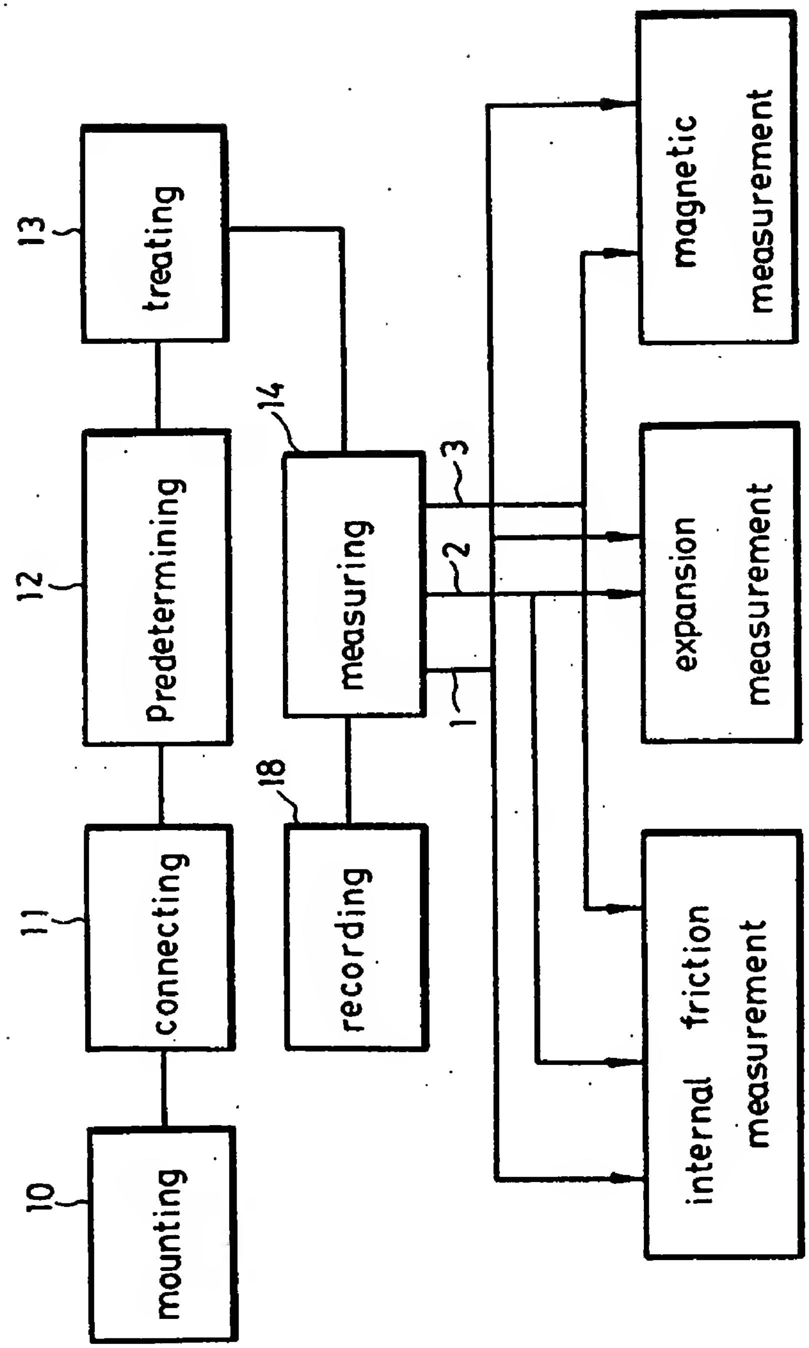

13
treating
12
Predetermining
11
connecting
10
mounting
14
measuring
18
recording
3
2
1
magnetic measurement
expansion measurement
internal friction measurement

FIG. 1

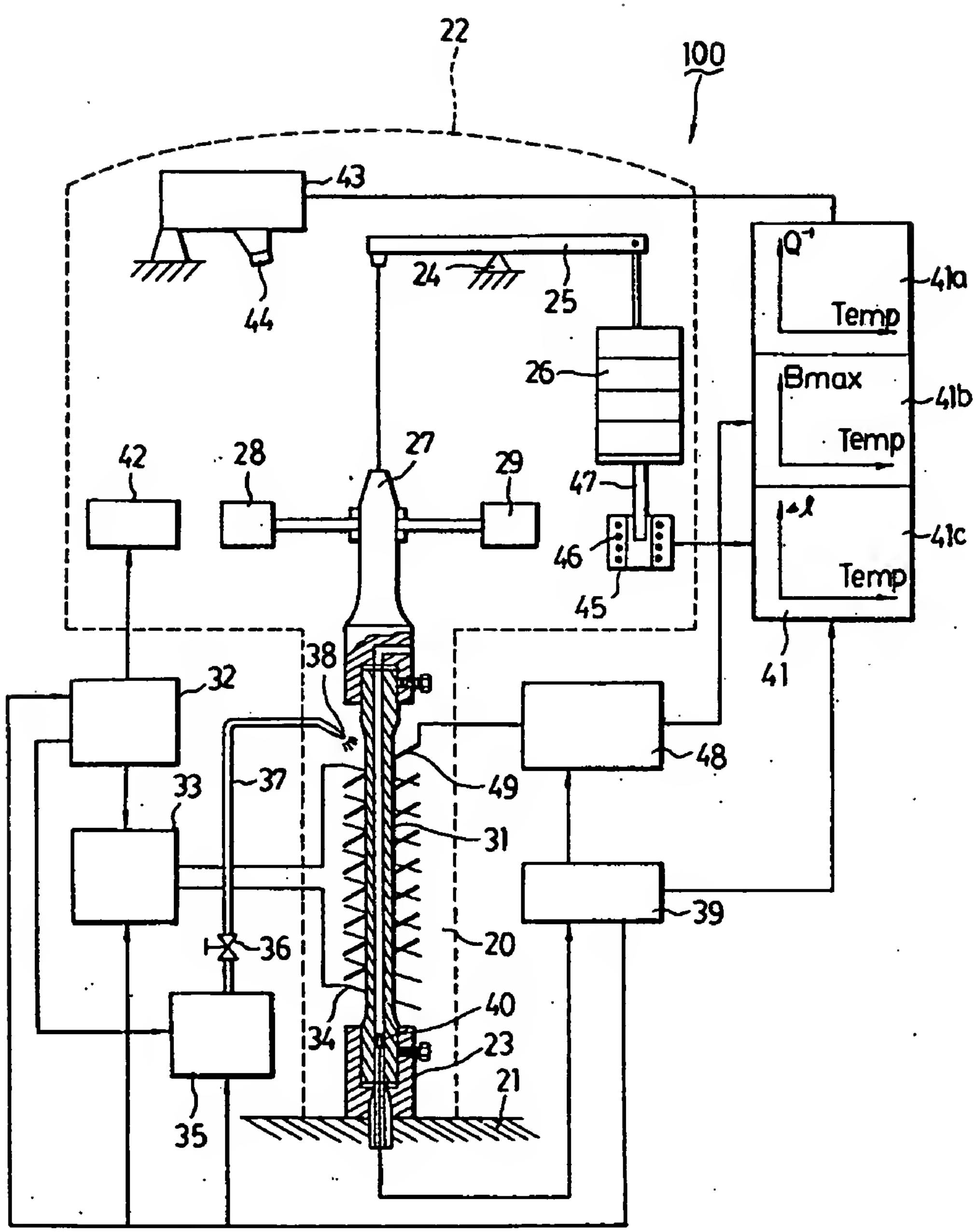

22
100
43
44
24
25
26
Q⁻¹
Temp
41a
Bmax
Temp
41b
Temp
41c
41
42
28
27
29
47
46
45
32
38
33
37
49
31
48
39
36
20
40
34
23
21
35

FIG. 2

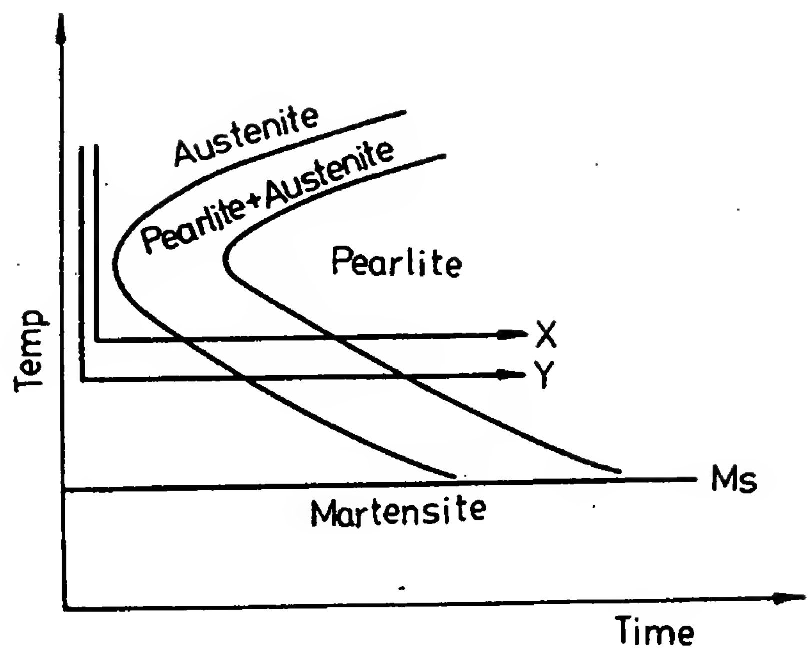

Austenite
Pearlite+Austenite
Pearlite
X
Y
Temp
Ms
Martensite
Time

FIG. 3

## APPARATUS FOR DETERMINING METAL PROPERTIES

This application is a continuation of application Ser. No. 212,520, filed June 28, 1988, now abandoned.

## BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an apparatus for determing the properties of metals an apparatus which measures the internal friction behavior of an alloy during its phase transformation.

2. Description of the Prior Art

The measuring techniques of internal friction that have been developed in the past few decades, i.e. the torsion pendulum method, the transverse vibration method and others for measuring internal friction behavior of metals, provide significant contributions to the study of metals. The techniques of measuring internal friction are used to measure the situations of solid solutions in a metal alloy, such as the solute content of nitrogen and/or of carbon in steel, the distribution and diffusion of some elements in an alloy, and other defects in a metal, etc. Therefore, due to the fact that those new techniques provide meaningful measured results of the inside situation of metals, persons in the art can now understand metals much better than before.

Although internal friction measuring has been widely applied in the study of metals, the measuring condition needs to be improved in at least two aspects. Firstly, during a heat-treatment, such as quenching, tempering, and annealing, metals are treated at several different temperatures which cause the structural change, but the internal friction measuring of the metal specimens has only been conducted after the whole heat treatment procedure has been completed. That is to say, for example, the known skills can't measure the internal friction behavior of the incubation period of a over cooled austenite of the transformations during the heat treatment, but only provides the measured data of heat treated specimens whose phase is in a steady and/or final state. Secondly, due to the limitation of experimental equipment, the known skills can not be performed at high temperatures, such as 750° C. to 1100° C. At these high temperatures known equipment can not measure the in-situ internal friction behavior of a metal specimen during the heat treatment procedure.

## SUMMARY OF THE INVENTION

Accordingly, the primary object of the present invention is to provide an apparatus for measuring the internal friction behavior of a metal alloy during the period of alloy phase transformation.

Another object of the present invention is to provide an apparatus for measuring both the internal friction behavior, and the expansion and/or magnetic property variation curve of a metal alloy during a heat treatment procceding so as to confirm whether the measurement is taken in the incubation period or other period of phase transformation of the metal.

Still another object of the present invention is to provide an apparatus for measuring the in-situ internal friction behavior of a metal alloy during a heat treatment proceeding.

Yet another object of the present invention is to provide an apparatus which conducts the measurements of the in-situ internal friction, expansion curve, and magnetic property variation curve of a metal alloy during heat treatment such that internal friction variations, from one phase to another, of the alloy can be clearly measured. In addition, the present apparatus can also perform the same task as the conventional one, that is measuring the internal friction of the heat treated metal alloy whose phase is in a steady state. These and other objects can be achieved by the provision of a combination comprising an internal friction measuring apparatus, a dialometer, a heating and cooling system, and a programmable controller to control the measurements and the heating and cooling system.

The features and characteristics of the present invention will become more obvious from the following detailed description of a preferred embodiment of the invention in conjunction with the drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a flow-chart of block diagrams for illustrating the steps conducted by the apparatus of this invetion;

FIG. 2 is a scheme for illustrating an embodiment of the apparatus of this invention; and

FIG. 3 is a chart of a time-temperature-transformation curve for illustrating the phase transformations of an iron-based alloy, in which lines X and Y are predetermined conditions, using the method of this invention to investigate the phase transformation for different periods with an isothermal in-situ measurement procedure.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. 1 a flow chart of the steps of measurements that can be conducted by the apparatus of this invention in which numeral **10** indicates a step of mounting a metal specimen on a measuring device; numeral **11** indicates a step of connecting a temperature measuring device, such as a thermal couple, to the metal specimen; numeral **12** indicates a step of predetermining a temperature variation pattern of the specimen by a programmable temperature controller; numeral **13** indicates a step of treating the metal specimen under the control of the temperature controller; numeral **14** indicates a step of measuring the in-situ internal friction behavior, expansion curve and/or magnetic property variation curve of the metal specimen; and numeral **18** indicates a step of recording the measured data so as to provide a better understanding of metals. In the heating step **12**, the metal specimen may be heated by several different treatments such as annealing, tempering or quenching. No matter what kind of heat treatment is used, the metal specimen is kept at its original position so that an in-situ measurement can be conducted. In the connecting step **11**, the temperature measuring device connected to the metal specimen must not cause any appreciable unexpected external friction to the metal specimen. This is in contrast to the torsion pendulum internal testing apparatus, in which the part of the specimen on which the thermal couple is connected will not experience any torsion, i.e. the place near the torsion center of the metal specimen and the place near the fixed end of the specimen. As a matter of fact, the connection between the thermal couple and the specimen is also one of the characteristics of the invention. The thermal couple, according to the invention, is preferably embeded into the fixed end of the specimen so as to get an accurate measurement, particularly during quenching proceedings. In the measuring step **14** one of three different combina-

tions of measurements can be selected, namely, the measurements of the internal friction, the expansion curve and the magnetic property variation curve indicated by numeral 1; measurements of the internal friction and the expansion curve indicated by numeral 2; or measurements of the internal friction and the magnetic property variation curve indicated by numeral 3.

Turning to FIG. 2, an apparatus 100 of this invention is shown, having a torsion internal friction testing device 20 provided in is a vacuum housing 22 is mounted on a supporting base 21 so that an internal friction measurement can be conducted under the vacuum condition. In the housing 22, a specimen mounting device 23 is provided on the supporting base 21. At the upper portion of the torsion internal friction testing device 20 a lever 25 is fulcrumed at a pointed support 24. A counter balance 26 is connected to end of the lever 25 and a torsion pendulum device 27 is suspended from the other end of the lever 25. A pair of arms 28, 29 are respectively extended from the torsion pendulum device 27 in opposite directions. At the lower portion of the torsion pendulum device 27 there is provided a second specimen mounting device 30 so that a bar-shaped metal specimen 31 can be mounted between the two mounting devices 23 and 30.

The apparatus 100 further comprises a programmable controlling device 32 by which a desirable pattern of measurement can be pre-determined. In other words, with the programmable controlling device 32, a user can select any one of the combinations of the measurements as described above in reference to FIG. 1. Furthermore, the programmable controlling device 32 can also predetermine the conditions of heating, cooling, and isothermal heating in the heat treatment of the metal specimen 31 so as to control the specimen 31 at a desired temperature during the entire measuring proceeding. A heating device 33 is controlled by the programmable controlling device 32 to heat the specimen 31 and can either be an electric heating wire 34 or an induction coil. A cooling device controlled by the programmable controlling device 32 includes a controlliing valve 36, a conduit 37 and nozzle 38. In the cooling operation, using the control valve 36, a cooling gas, such as liquid nitrogen, will be sprayed out of the nozzle 38 onto the heated specimen. A temperature measuring device 39 is connected with a thermal couple 40 whose one end is passed through the mounting device 23 and then embeded into the torsion center of the specimen 31 as clearly shown in FIG. 2. In this way, this connection between the thermal couple 40 and the specimen 31 will not cause an appreciable unexpected external friction to the metal specimen. The measured data of the temperature measuring device 39 will be provided not only to the programmable controlling device 32 but also to a recording device 41.

Preferably, the measurement conducted by the torsion internal friction testing device 20 is conducted under $10^{31\,2}$ to $10^{-3}$ Torr of vacuum.

A triggering device 42 is provided in the torsion internal friction testing device 20 and controlled by the programmable controlling device 32. The triggering device 42 will cause a torsion to the arms 28, 29 of the torsion pendulum device 27 until it equal to the natural frequency of the torsion pendulum of the metal specimen 31 so as to obtain the desired torsional vibration of the metal specimen 31. In addition, an internal friction measuring device 43 provided with a motion detecting device or photo-detector 44 measures the internal friction values of the metal specimen 31 and sends the measured data to the recording device 41. Therefore, after a heat treatment is applied to the metal specimen 31, a curve 41*a* showing the internal friction curve of the specimen can be obtained.

Since the damping of the triggered specimen 31 may be fast, some difficulties may be created in proceeding with the measurement. Thus, in accordance with the present invention, it is preferred that when the designed torsional vibration of the triggered specimen 31 is reached, an external energy be applied to make the triggered specimen keep its constant amplitude torisonal vibration. The value of the applied external energy should be the same as the value of the internal friction of the specimen. This novel apparatus of the present invention will render the internal friction measurement more accurate.

In addition, a dilatometer 45 includes a solenoid coil 46 connected with the recording device 41, and a core 47 suspended from the underside of the counter balance 26 and extended into the solenoid coil 46.

Following the variation of temperature during the heat treatment proceeding, the expansion of the specimen 31 will change, making the lever 25 more clockwise or counterclockwise, and making the core 47 move downward or upward. The dilatometer 45 will note the changes in magnetic conductivity which represent corresponding up and down movement of the core 47 and will send the resulting measured data to the recording device 41. Therefore, a curve 41*c* showing the relation between the variation of temperature and the expansion of the metal specimen will be obtained by the recording device 41.

The apparatus 100 according to this invention further comprises a magnetic detecting device 48 having induction coils 49 surrounding the metal specimen 31. Following the variation of temperature, the induction coils 49 will induce changes in the magnetic flux of specimen 31 and will send the data concerning these changes to the recording device 41. Therefore, a curve 41*b* showing the relation between the variation of temperature and the magnetic property of the specimen 31 can be obtained.

From the above described apparatus, it should be appreciated that due to the application of the programmable controlling device 32, one can easily predetermine the items and patterns of the measurement and the variation of temperature. According to this invention, the apparatus 100 is capable of not only measuring the internal friction behavior, expansion and/or the magnetic property change of the metal specimen during the heating, cooling and isothermal heating proceedings of the heat treatment, but also capable of keeping the specimen 31 in-situ while conduting those measurements. Thus, the apparatus provides a considerable amount of valuable measured data which can not be obtained with known skills and is significantly meaningful to the study of metals.

As an example, FIG. 3 shows a time-temperature-transformation curve of an iron-based alloy during heat treatment which illustrates the phase transformations of the alloy. By using the traditional apparatus, a skilled person may obtain the results of the phase transformations shown in FIG. 3.

However, various information cannot be obtained from the results. For instance, when the crystal structure of the iron-based alloy transform from the austenite phase into the pearlite phase, persons skilled in the art

find it difficult to get information during transformation process, especially, during such period of the incubation.

It is clearly shown in FIG. 3 that lines X and Y represent respectively, a specimen of an iron-based alloy cooled radily from a higher temperature to a lower temperature and then kept in an isothermal proceeding for a certain period. By using the apparatus of this invention disclosed previously, the detailed measurements of the internal friction of the iron-based alloy can be obtained not only in the situation of a single phase but also in process of phase transformation, such as the austenite range to the range of austenite and perlite, and then eventually to perlite range. In other words, according to this invention, after changes of the magnetic flux and/or expansion curve are measured, one will know that the phase transformation has been effected. Therefore, the obtained values of the internal friction of the alloy before, during, and after the phase transformations will be significantly useful for the further study of metal.

It should be understood that any person skilled in the art may make some minor modifications in light of the previous description of this invention. However, such modifications shall fall into the scope of the appended claims.

What is claimed is:

1. An apparatus for determining in-situ an internal friction of a metal specimen comprising: a vacuum housing means for mounting a metal specimen in said vacuum housing, said mounting means having means for fixing one end of said metal specimen, a fulcrumed lever provided above said fixing means, means for hanging the other end of said metal specimen on one end of said lever, and a weighing member attached to the other end of said lever; an internal friction measuring means; means for heating said metal specimen at a controlled heating rate; means for cooling said metal specimen at a controlled cooling rate; means for measuring the temperature of said metal specimen; an electromagnetic dialometer connected to said weighing member for determining the thermal expansion of said metal specimen; means for determining the varying internal friction of said metal specimen; and a control means connected to said temperature measuring means, said heating means, said cooling means and said internal friction measuring means for controlling the temperature of said metal specimen and for controlling said internal friction measuring means to determine varying values of the internal friction at certain controlled temperatures; and means for recording the varying thermal expansion of said metal specimen connected to said electromagnetic dialometer.

2. An apparatus as claimed in claim 1, further comprising means for determining the magnetic properties of said metal specimen at said certain controlled temperatures, said magnetic property determining means connected to said control means.

* * * * *

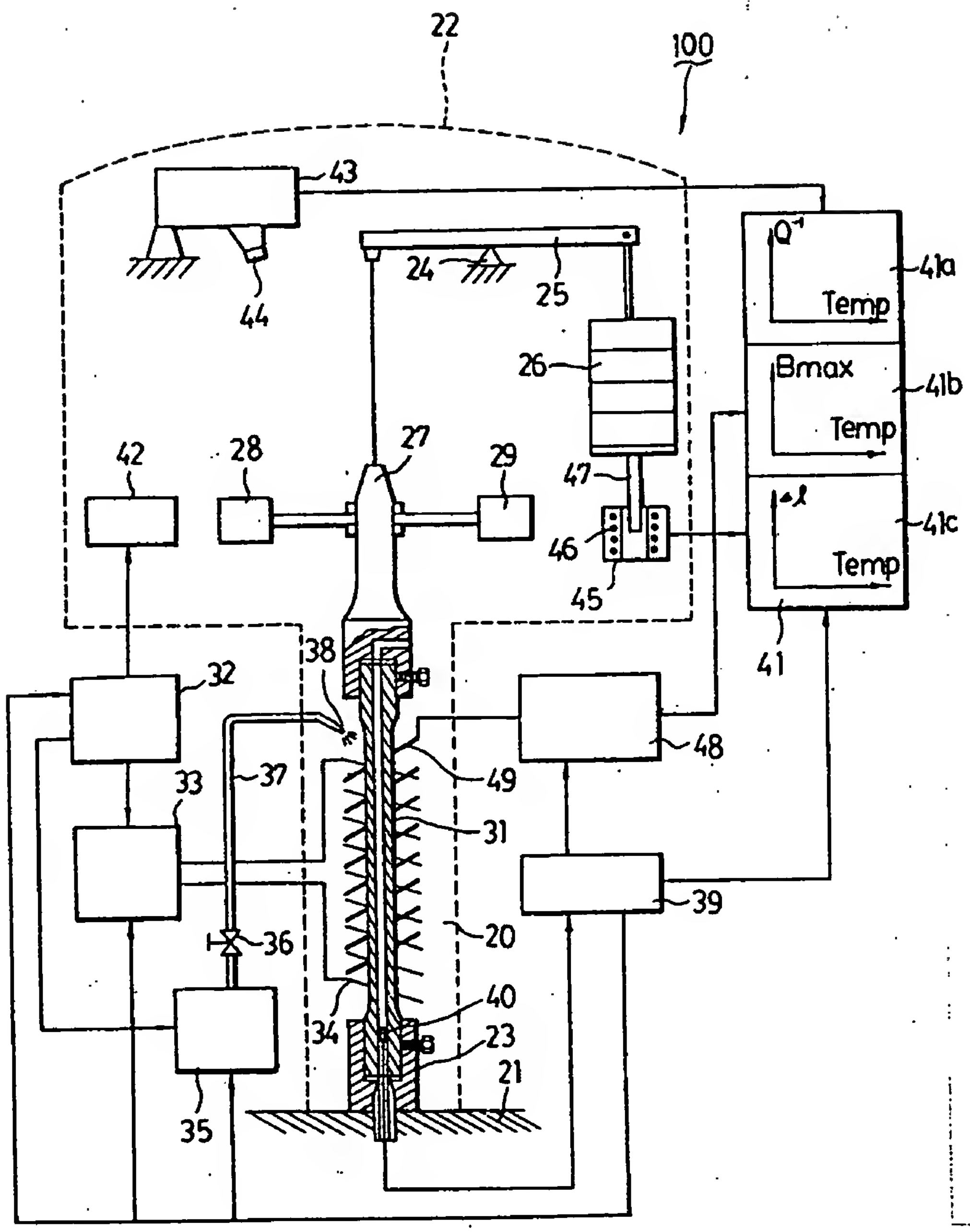

22
100
43
44
24
25
26
$Q^{-1}$
Temp
41a
Bmax
Temp
41b
ℓ
Temp
41c
41
42
28
27
29
47
46
45
38
32
48
33
37
49
31
39
36
20
40
34
23
21
35

FIG. 2

US-PAT-NO: 5708253

DOCUMENT-IDENTIFIER: US 5708253 A
**See image for Certificate of Correction**

TITLE: Apparatus and method for computerized interactive control, measurement and documentation of arc welding

---------- KWIC ---------

Brief Summary Text - BSTX (16):
To ensure compliance with the foregoing, the regulations advise, and often require, that such **temperature** readings be **recorded** in graphical or tabular form. Documentation of pre, interpass and post weld temperatures and other variables is therefore of critical importance to assure compliance with applicable regulations. Such documentation is also valuable in non-regulated situations where economic or other considerations generate a need to assure weld quality by control of welding process variables. Weld joint failure may lead to mechanical failures, leakage of hazardous or dangerous products or merely the requirement to grind away poor weld material and repeat all or part of the weld process.

Brief Summary Text - BSTX (18):
Commonly, electric resistance power sources utilized for workpiece heating

are completely separate from the welding power source. In other cases, a welding power source can be equipped with a **temperature** controller and devices to monitor and **record temperatures** necessary to provide workpiece heating. A few examples of a separate power source having specialized control units for the workpiece operations include standard equipment manufactured by: Cooperheat of Piscataway, N.J.; Hill Technical Services, Inc. of Houston, Tex.; Mannings USA of Morristown, N.J.; Global Heat of Concord, Calif., and others. Examples of such dual purpose power sources which utilize welding power sources to provide power for workpiece operations include units developed by John Hill of Control and Inspection Services of Houston, Tex. and Richter Industries, Inc. of Scottsdale, Ariz.

Brief Summary Text - BSTX (19):

Although these prior art means for controlling and monitoring **temperatures** during the welding process have proved sufficient to elevate, control and **record temperature** of the workpiece operation, they all share one or more of the following deficiencies: (1) requirement of separate equipment such as gas bottles, hoses, regulators and the like, for example in workpiece operations which utilize flame type torches; (2) requirement of separate power sources, often adversely affecting the power supply to the welding operation power source and requiting manual switching of power sources; (3) lack of operational interactivity between the power sources for

workpiece operation and welding operation; (4) lack of contemporaneous monitoring of welding operation parameters, actual welding operation source output, workpiece operation parameters and actual workpiece operation **temperatures**; and/or (5) lack of detailed **record** or contemporaneous feedback of workpiece and welding operational parameters to the welding operator or the welding quality control inspector.

Brief Summary Text - BSTX (23):
The apparatus of the present invention also allows automatic adjustment of power settings to be programmed into the computerized workpiece power source to adjust the welding operation power source output as a function of changes in the workpiece temperature. Real-time monitoring and **recording** of key parameters, such as workpiece **temperature,** and the welding operation power source output voltage and current, is accomplished by a computer controller, providing a complete log of the welding operation for qualification of weld procedures, training, and quality control compliance verification.

Brief Summary Text - BSTX (26):
The method of the present invention is utilized not only to achieve precision arc welding, but is also used to: (1) prequalify weld operators by monitoring the ability of the weld operator to control actual arc energy values including current and voltage against preset

values; (2) train weld operators utilizing the monitoring and **record** of the operator's ability to control arc energy values including actual current and voltage against preset values for different weld procedure conditions and positions; (3) improve the performance of weld operators by providing real time audible or visual feedback indicating to the weld operator actual weld energy power values including voltage and current versus preset values as well as workpiece operation parameters such as workpiece **temperature**; (4) contemporaneously monitor the performance of both welding and workpiece-operations, as well as welder performance, to provide greater assurance of the consistent performance of precision welding; and (5) monitor and **record** both preset and actual critical weld and workpiece operation parameters to facilitate greater assurance of the consistent performance of precision welding that conforms to preset optimum conditions.

US005708253A

# United States Patent [19]

**Bloch et al.**

[11] **Patent Number: 5,708,253**

[45] **Date of Patent: Jan. 13, 1998**

[54] **APPARATUS AND METHOD FOR COMPUTERIZED INTERACTIVE CONTROL, MEASUREMENT AND DOCUMENTATION OF ARC WELDING**

[75] Inventors: **Christopher J. Bloch**, Kingswood; **Don Harrison**; **John Hill**, both of Houston, all of Tex.

[73] Assignee: **Hill Technical Services, Inc.**, Houston, Tex.

[21] Appl. No.: **476,780**

[22] Filed: **Jun. 7, 1995**

[51] **Int. Cl.**[6] .................................... **B23K 9/095**

[52] **U.S. Cl.** .................... **219/130.01**; 219/130.21; 219/132; 219/137 PS

[58] **Field of Search** .................. 219/130.01, 130.21, 219/132, 137 PS, 483; 228/103

[56] **References Cited**

U.S. PATENT DOCUMENTS

| | | | |
|---|---|---|---|
| 2,276,643 | 3/1942 | Bates | 219/483 |
| 3,560,712 | 2/1971 | Toohill | 219/483 |
| 3,851,141 | 11/1974 | Cooper | 219/132 |
| 4,103,141 | 7/1978 | Wristen . | |
| 4,359,622 | 11/1982 | Dostoomian et al. . | |
| 4,375,026 | 2/1983 | Kearney . | |
| 4,385,223 | 5/1983 | Thommes . | |
| 4,447,703 | 5/1984 | Stol . | |
| 4,578,562 | 3/1986 | Lindström et al. . | |
| 4,605,836 | 8/1986 | Retfalvi et al. | 219/130.01 |
| 4,721,947 | 1/1988 | Brown | 228/103 |
| 4,973,814 | 11/1990 | Kojima et al. . | |
| 5,140,123 | 8/1992 | Mitani . | |
| 5,223,683 | 6/1993 | Ishizaka . | |
| 5,278,382 | 1/1994 | Rische et al. . | |
| 5,302,799 | 4/1994 | Kennedy et al. . | |
| 5,317,125 | 5/1994 | Rossi . | |
| 5,319,179 | 6/1994 | Joecks et al. . | |

OTHER PUBLICATIONS

Byrd, "Inverter Power Sources: An Efficient Alternative", *Welding Journal*, 1/1993, pp. 37–40.

"For the Welding Industry", Control and Inspection Services, Inc.

"75 KVA Heat Treatment Centre", Control and Inspection Services, Inc.

"Heat Treating and Welding Products for Industry", Richter Industries, Inc.

"P135–6 Heat Treatment Control Centre", Global Heat.

"Modern Welding Technology", Howard B. Cary, 1981, pp. 264–266.

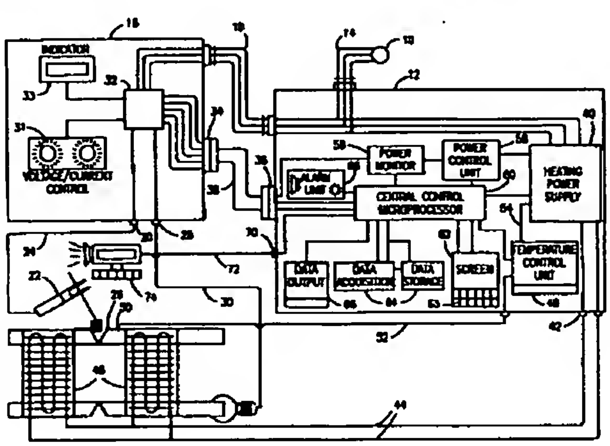
(List continued on next page.)

*Primary Examiner*—Clifford C. Shaw
*Attorney, Agent, or Firm*—Jenkens & Gilchrist, P.C.; J. Kevin Gray

[57] **ABSTRACT**

An apparatus and method for computerized interactive control, measurement and documentation of arc welding utilizing a single power source that facilitates continuous precision welding. Operational interactivity between the welding operations and the workpiece operations, in connection with predetermined optimum welding operational parameters, provides contemporaneous feedback of critical welding operational parameters to the welding operator, producing an alarm if welding is attempted outside a first predetermined range of deviation from optimum welding operational parameters and temporarily interrupting power to the welding operation if welding is attempted outside of a second predetermined range of deviation from the optimum welding operation parameters. A complete log of the welding operational parameters is stored for subsequent retrieval and display, providing training and evaluation of welding operators as well as verification of compliance with required welding practices and procedures. Methods of performing continuous precision welding, facilitating temperbead welding, training and qualifying welders for such operations and verifying practice and procedure compliance are available utilizing the above-described apparatus.

**61 Claims, 3 Drawing Sheets**



## OTHER PUBLICATIONS

"Welding Handbook", American Welding Society, 1987, vol. 1, pp. 77–79, 473; vol. 2, pp. 9–11, 31, 84, 238, 206–207, 253–255, 288, 370.
"Heat Treatment Equipment Guide", Cooperheat, 1985.
"Thermal Engineers", Mannings, 1989.
"Products and Services", Cooper Heat (UK), Ltd., 1986.
"The Inverter Welding Power Source", Tech Talk, reprinted, Spring 1987, MEMCO News a/k/a Miller Electric Mfg. Co., Marv Schiedermayer, 1987.
"6–Way Power Source", Cooperheat, 1994.
"Three Mode Programmer", Control and Inspection Services, Inc.
"MA–8Z Heat Controller", Heating and Welding Chart, Richter, 1991.
"Richter Heat Controller", Model MA–8Z, General Specifications, Richter Industries, Inc.
"A New Revolutionary Heat Controller From Richter Industries", Richter Industries, Inc.
"Small, Mighty Inverters Deliver Big Benefits" Special Report, Welding Design & Fabrication Magazine, Apr. 1994.
"Inverters Help Welders Deposit Tons of Filler", Gene H. Steen, Jr. and Eugene B. Roy, Welding Design & Fabrication Magazine, Apr. 1994.
"Stresstech", Preheating and Post Weld Heat Treatment Equipment Manual.
"Accessories for Electrical Heat Treating" Brochure, Hill Technical Services, Inc., Rev. 08/94.

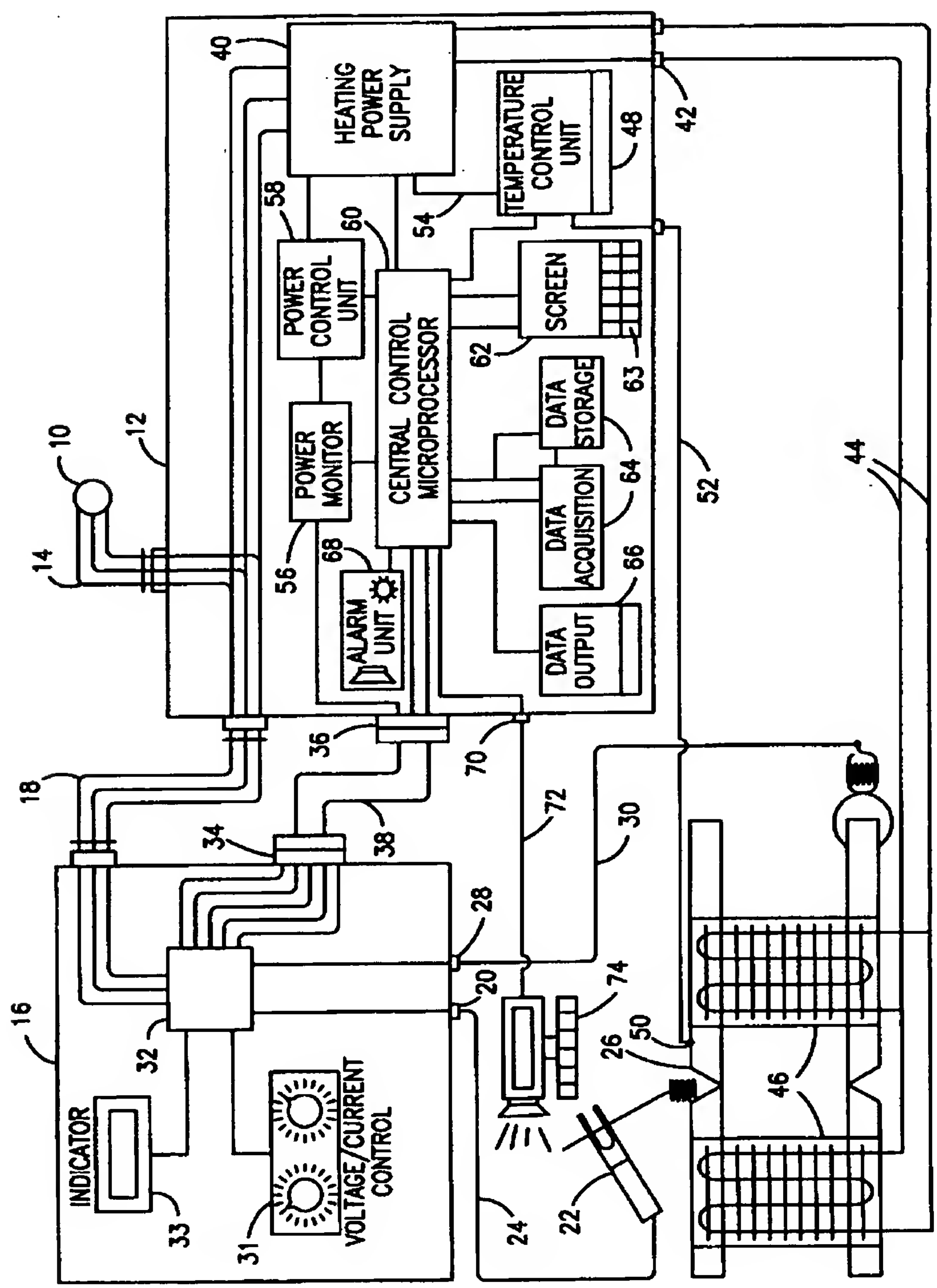

HEATING POWER SUPPLY
TEMPERATURE CONTROL UNIT
POWER CONTROL UNIT
CENTRAL CONTROL MICROPROCESSOR
SCREEN
POWER MONITOR
DATA STORAGE
DATA ACQUISITION
ALARM UNIT
DATA OUTPUT
INDICATOR
VOLTAGE/CURRENT CONTROL

FIG. 1

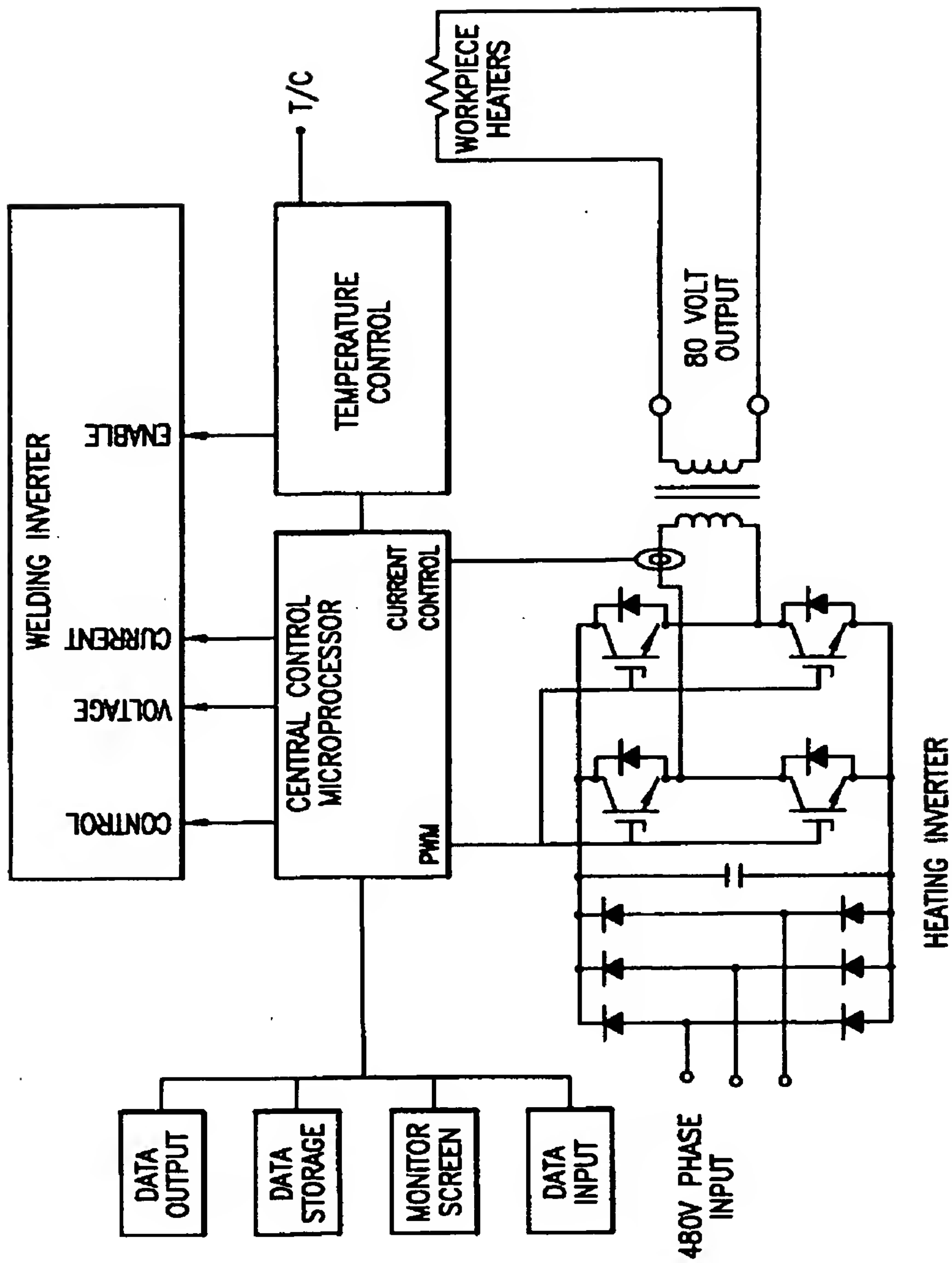

WELDING INVERTER
ENABLE
CURRENT
VOLTAGE
CONTROL
T/C
TEMPERATURE CONTROL
CENTRAL CONTROL MICROPROCESSOR
CURRENT CONTROL
PWM
WORKPIECE HEATERS
80 VOLT OUTPUT
HEATING INVERTER
480V PHASE INPUT
DATA OUTPUT
DATA STORAGE
MONITOR SCREEN
DATA INPUT

FIG. 2

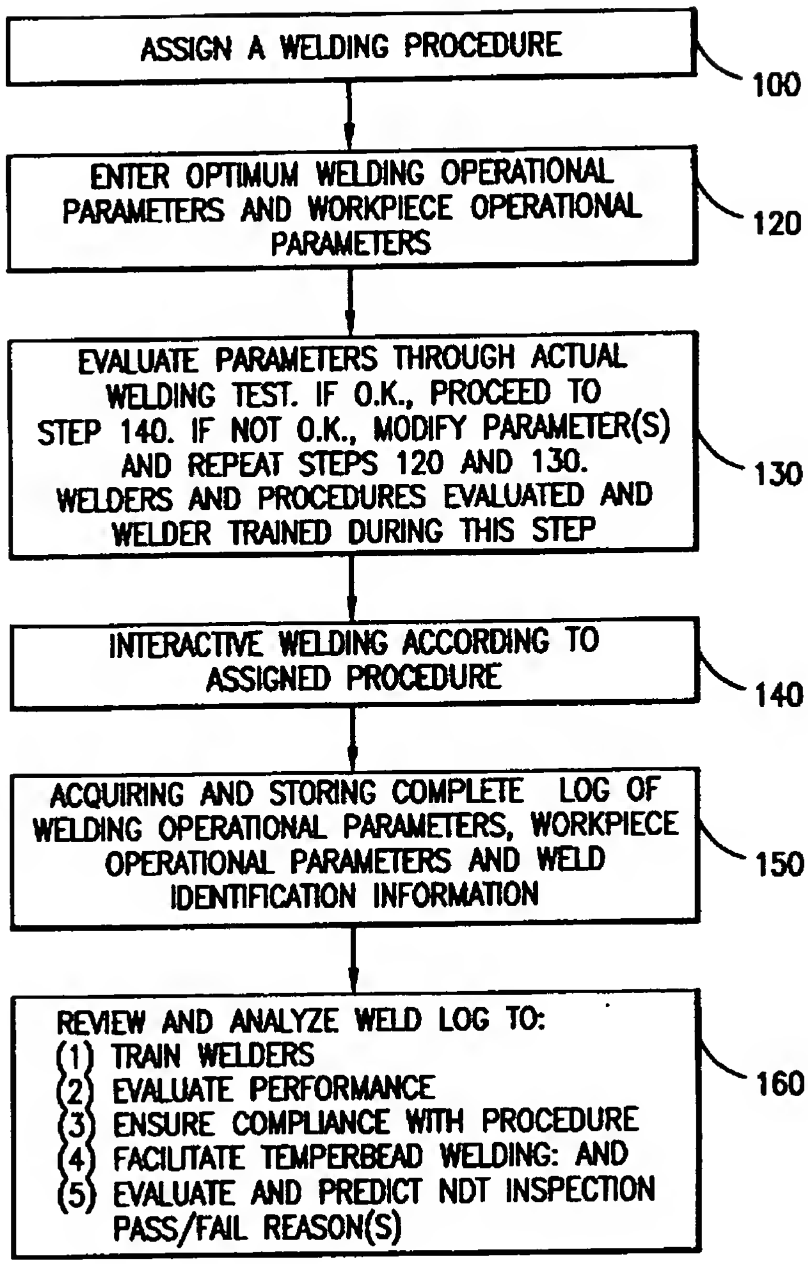

ASSIGN A WELDING PROCEDURE
100
ENTER OPTIMUM WELDING OPERATIONAL PARAMETERS AND WORKPIECE OPERATIONAL PARAMETERS
120
EVALUATE PARAMETERS THROUGH ACTUAL WELDING TEST. IF O.K., PROCEED TO STEP 140. IF NOT O.K., MODIFY PARAMETER(S) AND REPEAT STEPS 120 AND 130. WELDERS AND PROCEDURES EVALUATED AND WELDER TRAINED DURING THIS STEP
130
INTERACTIVE WELDING ACCORDING TO ASSIGNED PROCEDURE
140
ACQUIRING AND STORING COMPLETE LOG OF WELDING OPERATIONAL PARAMETERS, WORKPIECE OPERATIONAL PARAMETERS AND WELD IDENTIFICATION INFORMATION
150
REVIEW AND ANALYZE WELD LOG TO:
(1) TRAIN WELDERS
(2) EVALUATE PERFORMANCE
(3) ENSURE COMPLIANCE WITH PROCEDURE
(4) FACILITATE TEMPERBEAD WELDING: AND
(5) EVALUATE AND PREDICT NDT INSPECTION PASS/FAIL REASON(S)
160

FIG. 3

# APPARATUS AND METHOD FOR COMPUTERIZED INTERACTIVE CONTROL, MEASUREMENT AND DOCUMENTATION OF ARC WELDING

## TECHNICAL FIELD

This invention relates to welding and, more particularly, to an apparatus and method for precision welding utilizing a single power supply and operational interactivity between the welding power source and a pre-, post and interpass heat control device for quality assured performance of critical welds.

## BACKGROUND OF THE INVENTION

The permanent union of metal by arc welding is widely practiced in a myriad of industries. The quality of such welding is a function of many complex factors including the skill of the welding operator, the temperature of the arc, the temperature of the workpiece, the presence of contaminants, the internal chemical makeup of the metal in question, etc. While it is impossible to perfectly control all such factors, the quality of welding is often of critical importance. Of obvious importance are situations where the public welfare and safety rest in part on the quality of the welded joint. Welds used in critical components of a nuclear power plant, fossil fueled power plants, refineries, pipe lines, chemical plants and steel reinforced structures in regions with seismic activity are but a few examples. Accordingly, the federal and many state governments heavily regulate the practices and procedures associated with such welding operations. Examples of such practices include: ASME Boiler and Pressure Vessel Code; Section 1, "Rules for Construction of Power Boilers;" Section III, "Rules for Construction of Nuclear Power Plant Components;" Section VIII, "Rules for Construction of Pressure Vessels;" Section IX, "Welding and Brazing Qualifications;" ANSI B31.1, "Power Piping;" and ANSI B31.3, "Chemical Plant Piping." In addition to these are many practices and procedures recommended by professional organizations such as the American Welding Society (AWS) and the American Petroleum Institute (API).

Since the mechanical qualities of a weld are, in part, a function of maintaining a proper temperature in and around the weld location, many regulations require that the workpiece be preheated to a specific temperature range prior to the welding operation. Others also require that the workpiece be maintained within a particular temperature range between successive applications of weld metal achieved through repeated passes of the welding electrode over the weld joint (the interpass). Still other standards require heating welds to specific temperature ranges for specific time periods following the welding operation (post-heating).

Control and monitoring of these pre-, interpass and post-heating temperatures is typically accomplished in one of several ways. These method include: (1) application of a torch flame to the metal workpiece; (2) electrical resistance heating elements secured to the metal workpiece; (3) induction heating coils applied to the workpiece; and (4) radiant infrared heating lamps or elements applied to or near the workpiece.

The joining of metal parts in critical applications can be divided roughly into two operations: (1) the welding operation; and (2) the workpiece operation. For purposes of this Application, the term "welding operation" will refer to the heating of the workpiece surface and a filler metal at the point of joining by means of an electrical arc sufficient to melt both the surface of the workpiece and the filler metal, wherein the combined pool of molten metal will subsequently cool to form one continuous mass of metal. For the purpose of this Application, the term "workpiece operation" will refer to supplemental pre-, interpass and post-heating of the subject workpiece adjacent to and including the weld joint.



In the "welding operation" referred to in this application, the temperatures necessary to melt both the workpiece surface and the filler metal are achieved by means of an electric arc. Precision control of the arc energy is critical to this operation. Inadequate arc energy will not generate temperatures sufficiently hot to achieve complete melting of the workpiece surfaces. In such cases, the solidifying molten metal pool will not continuously fuse to the workpiece. Excessive arc energy will provide adequate temperatures to melt both the workpiece surfaces and the filler metal, however, it may also result in "arc blow-through" of the weld area, the generation of excessive splatter of the molten metal and other undesirable conditions. The welding operator can control arc energy to regulate the weld pool temperature through the careful adjustment of the travel speed and movement of the arc and by manipulation of the voltage and current settings of the welding power source.

Even in the hands of a skilled welding practitioner, there are numerous conditions which frustrate a continuous fusion of the metal workpiece surfaces free of cracks, voids, slag inclusions and other defects. Among the conditions which generate faulty weld bonds are:

(1) Rapid cooling of the weld pool and the adjoining metal (typically referred to as the Heat Affected Zone (HAZ)). This condition produces cracks which form due to stresses generated by the volumetric shrinkage of the metal as the molten metal rapidly cools. As the metal cools and shrinks it generates tension stresses. These stresses can often be sufficiently great as to exceed the yield or tensile strength of the weld metal or the HAZ metal, resulting in distortion or possible failure. The tendency for metal to crack is increased by the presence of atomic hydrogen. Atomic hydrogen increases the tendency of the metal to become brittle, therefore increasing its propensity to crack. One way in which atomic hydrogen is formed is through moisture or hydrocarbon contamination being exposed to the high temperatures generated by the electrical arc. To minimize atomic hydrogen it is common practice to clean the surface to be welded and to eliminate moisture from the surfaces by heating (preheat). Cracking of the weld metal and the HAZ is more likely in certain alloy and high carbon steels due to their intrinsic brittleness. Raising the temperature of the weldment (preheat) typically increases the ability of the metal to flex or stretch without cracking. It is often important to maintain such an elevated temperature throughout the welding process (maintain interpass temperature) to prevent loss of ductility thus preventing crack formation.

Heating of the weld and workpiece metal following the welding process to an elevated temperature sufficient to allow the metal to plastically deform will relieve stresses induced by the weld process. This post weld heat treating, (PWHT), is commonly prescribed to prevent cracking of the weld and HAZ metal. Relief of weld induced stresses is also practiced in situations where the weld will be exposed to a corrosive environment such that accelerated corrosive attack would occur at the highly stressed metal region; and

(2) Inclusion of excessive gaseous voids in the weld metal. The action of the electrical arc on the molten metal pool during the welding operation and the agitation generated by the arc and the dropping of molten

filler metal into the weld pool often results in tiny bubbles of gas mixing into the molten metal. This gas can be entrained in the molten metal from the immediate atmosphere around the arc or can result from hydrogen generated by the arc due to the presence of moisture or hydrocarbons on the weldment surfaces or on the surface of the electrode or filler metal. Again, with proper arc energy settings and with a skilled weld operator the molten pool of metal formed by the melting of the workpiece surfaces and the molten filler metal will be allowed to solidify without excessive disruption and over sufficient time (typically a fraction of a second to several seconds) to allow entrained gases to separate from the molten metal. The presence of excessive void concentrations is frequently observed at locations where the weld process is started or stopped. This condition occurs in part due to the absence of arc energy being applied immediately before or immediately after the start/stop point. As a result of the lower energy flux, the molten weld pool will tend to solidify more rapidly, thus trapping additional gases in the weld joint. The application of preheat and interpass heat will slow the rate of molten metal solidification particularly during starts and stops. Sufficient preheat and interpass temperatures will also result in lower concentrations of voids in the weld metal generated by concentrations of atomic hydrogen in the weld metal and HAZ metal due to the fact that atomic hydrogen will diffuse out of metal at more rapid rates as temperatures are elevated.

In most arc welding processes a flux is introduced to provide a physical barrier between the molten weld metal pool and the environment. The flux melts and floats on the surface of the weld pool. The flux helps to shield the molten weld metal from atmospheric oxygen which could otherwise oxidize the weld metal. The flux also helps to limit the rate of heat loss due to radiation of heat from the weld pool. Once the flux cools it solidifies as a slag deposit. With improper arc energy settings, poor technique, or too rapid a rate of weld pool solidification, some of the slag becomes entrapped in the weld metal. Again preheat and interpass heating slow the rates of weld metal cooling, giving more time for the slag to completely separate from the weld metal. Subsequent removal of slag deposits by means of chipping, grinding and steel wire brushing is facilitated by proper rates of weld pool solidification and elevated workpiece temperatures. Complete removal of slag deposits between successive additions of weld metal improve weld joint quality.

In some cases, even when the stresses generated in the welded workpiece are not sufficient to crack the metal, the localized stress many combine with caustic or otherwise corrosive conditions to which the welded metal will be exposed to result in stress corrosion cracking or stress induced localized corrosion. Practitioners skilled in the art have learned that the PWHT of weldments exposed to such environments will greatly reduce the occurrence and extent of such corrosion.

To avoid these and other failure conditions, the previously mentioned codes and regulations often require control, monitoring and documentation of temperatures imparted by the welding and workpiece operations. Traditionally, monitoring has been accomplished in a variety of ways, including utilizing crayons, which melt or change color with temperature, thermocouples or infrared temperature indicators, to name just a few.

To ensure compliance with the foregoing, the regulations advise, and often require, that such temperature readings be recorded in graphical or tabular form. Documentation of pre, interpass and post weld temperatures and other variables is therefore of critical importance to assure compliance with applicable regulations. Such documentation is also valuable in non-regulated situations where economic or other considerations generate a need to assure weld quality by control of welding process variables. Weld joint failure may lead to mechanical failures, leakage of hazardous or dangerous products or merely the requirement to grind away poor weld material and repeat all or part of the weld process.



The heat utilized for the workpiece operation is typically supplied by a separate power or heat source from the welding operation power source utilized to generate the electric arc. Often this source is a torch or an electric resistance power supply. One advantage of separate electric resistance power sources is that they are often designed to control, monitor and document the preheat and interpass temperatures. The post-weld heat treating is commonly achieved by means of placing the work in a furnace or by means of wrapping the weldment in electric resistance heating elements which are often controlled, monitored and documented by the same power source used for supply of the preheat and interpass heating. Supply, maintenance and operation of separate heating sources for the workpiece operation typically involve the use of expensive equipment and add complexity to the welding process.

Commonly, electric resistance power sources utilized for workpiece heating are completely separate from the welding power source. In other cases, a welding power source can be equipped with a temperature controller and devices to monitor and record temperatures necessary to provide workpiece heating. A few examples of a separate power source having specialized control units for the workpiece operations include standard equipment manufactured by: Cooperheat of Piscataway, N.J.; Hill Technical Services, Inc. of Houston, Tex.; Mannings USA of Morristown, N.J.; Global Heat of Concord, Calif., and others. Examples of such dual purpose power sources which utilize welding power sources to provide power for workpiece operations include units developed by John Hill of Control and Inspection Services of Houston, Tex. and Richter Industries, Inc. of Scottsdale, Ariz.

Although these prior art means for controlling and monitoring temperatures during the welding process have proved sufficient to elevate, control and record temperature of the workpiece operation, they all share one or more of the following deficiencies: (1) requirement of separate equipment such as gas bottles, hoses, regulators and the like, for example in workpiece operations which utilize flame type torches; (2) requirement of separate power sources, often adversely affecting the power supply to the welding operation power source and requiting manual switching of power sources; (3) lack of operational interactivity between the power sources for workpiece operation and welding operation; (4) lack of contemporaneous monitoring of welding operation parameters, actual welding operation source output, workpiece operation parameters and actual workpiece operation temperatures; and/or (5) lack of detailed record or contemporaneous feedback of workpiece and welding operational parameters to the welding operator or the welding quality control inspector.

Thus a need has risen for an apparatus and method which will facilitate the consistent performance of precision welding, providing and utilizing operational interactivity between the welding power source function, the welding operation, the application, control, monitoring and documentation of the function of the workpiece operation heating power source and the workpiece operation as well as con-

temporaneous feedback to the welding operator and welding quality control inspector.

## SUMMARY OF THE INVENTION

The instant invention overcomes the foregoing and other problems associated with the prior art by providing an apparatus and method to facilitate the consistent performance of precision welding wherein a single primary power supply can be used to power both the welding operation and workpiece operation of the welding process. The invention consists of an apparatus and method for precision welding which includes operational interactivity between the welding operation and the pre-, post and interpass heating components (workpiece operations) of welding. Attempts at welding occurring outside a predetermined temperature range are audibly and/or visually identified to the weld operator and/or the weld quality control inspector. Attempts at welding occurring outside a second predetermined temperature range are precluded via temporary interruption of power for welding operations by the controller of the present invention.

The apparatus of the present invention also allows automatic adjustment of power settings to be programmed into the computerized workpiece power source to adjust the welding operation power source output as a function of changes in the workpiece temperature. Real-time monitoring and recording of key parameters, such as workpiece temperature, and the welding operation power source output voltage and current, is accomplished by a computer controller, providing a complete log of the welding operation for qualification of weld procedures, training, and quality control compliance verification.

The apparatus of the present invention also provides a means of giving the weld operator and weld quality inspector contemporaneous feedback on critical welding operation parameters. This feature provides pre, interpass and post weld temperature control from a single power supply without interference with the welding power source and control of welding arc stability. The apparatus is also configured to allow independent use of the welding power source and the heat control power source without interference to welders, motors or other electrical equipment serviced on the same power main. Prior art devices lack this ability to interactively provide power without interference to other electrical equipment.

The method of the present invention used with the above-described apparatus includes the pre-selection of optimum workpiece temperatures, the setting of temperature limits above and below which the operator is alerted that optimum conditions are not present, the setting of a second set of limits above and below which the power supply for the welding operation is temporarily interrupted, and the programming of the automatic adjustment of power settings of the welding operation power source output as a function of workpiece temperature, optimizing the selection of welding variables including type of weld method, welding operation power source output settings, electrode diameters, workpiece parameter settings, and other variables to achieve the most desirable welded joint during prequalification of the weld procedure.

The method of the present invention is utilized not only to achieve precision arc welding, but is also used to: (1) prequalify weld operators by monitoring the ability of the weld operator to control actual arc energy values including current and voltage against preset values; (2) train weld operators utilizing the monitoring and record of the operator's ability to control arc energy values including actual current and voltage against preset values for different weld procedure conditions and positions; (3) improve the performance of weld operators by providing real time audible or visual feedback indicating to the weld operator actual weld energy power values including voltage and current versus preset values as well as workpiece operation parameters such as workpiece temperature; (4) contemporaneously monitor the performance of both welding and workpiece operations, as well as welder performance, to provide greater assurance of the consistent performance of precision welding; and (5) monitor and record both preset and actual critical weld and workpiece operation parameters to facilitate greater assurance of the consistent performance of precision welding that conforms to preset optimum conditions.

## BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the invention may be had by reference to the following Detailed Description when taken in conjunction with the accompanying Drawings in which:

FIG. 1 is a schematic diagram of the apparatus of the present invention used in conjunction with an inverter type welding machine;

FIG. 2 is a circuit diagram of the control logic circuitry of the apparatus of the present invention; and

FIG. 3 is a flow diagram of the steps included in the method of the present invention disclosed herein.

## DETAILED DESCRIPTION

Referring now to FIG. 1, there is shown a schematic diagram of the present invention apparatus. A single power supply 10 is connected to a power source controller 12 by means of a power supply cable 14. For purposes of illustration only, the power supply 10 is a 460 volt, three-phase, 30 amp source. It should be noted that any suitable power supply can be used, if desired.

A welding power source 16 is connected to the power source controller 12 by means of a second power cable 18. The welding power source 16 converts power provided via the power source controller 12 from the power supply 10 to a higher amperage, lower voltage supply suitable for arc welding. In a preferred embodiment, the power source controller 12 is a WELDSMART™ unit and the welding power source 16 is an inverter type welding machine such as a Miller model XMT-300. The Miller XMT-300 welding power source is rated at 300 amps output. At full load it requires a maximum input of 21 amps of 460 volt three-phase power. Importantly, the power source controller 12 provides power without interfering with the power supply to other electrical equipment operating on the same power main due to switching transients or unbalanced phase loadings.

The welding power source 16 is further connected through a power tap 20 to a welding torch 22 by a welding lead 24. A workpiece 26 is connected to a return tap 28 of the welding power source 16 by a return lead 30. The welding power source 16 is equipped with controls 31 for voltage and/or current (amperage) and circuitry 32 which monitors actual voltage and/or current. A display 33 on the welding power source 16 visually presents the actual voltage and/or current during welding operation. The welding power source 16 is further equipped with a multi-pin port 34 which is utilized to remotely set and monitor the functions of the

voltage/current control and monitoring circuits 31 & 32. In a preferred embodiment, the multi-pin port 34 is connected to a similar second multi-pin port 36 on the power source controller 12 by a multi-wire control cable 38.

The power source controller 12 includes a heating power supply 40 which is connected through heating power source connector 42 via heating power leads 44 to the means for heating the workpiece 46. The means for heating a workpiece 46 are placed around the workpiece 26 adjacent to the site of the weld. Although the means for heating a workpiece 26 are illustrated as resistance heating pads, any suitable means for heating a workpiece, such as means using radiant heat or induction heating, can be utilized, if so desired. As power is provided to the means for heating a workpiece 46, the temperature of the workpiece 26 is raised to facilitate welding. The provision and precise control of the temperature of a workpiece before, during and following an actual weld procedure is critical to the quality of the resultant weld. In a preferred embodiment, the heating power source output is regulated to a maximum of 85 volts of alternating current. Additionally, the power source controller 12 draws on all three phases of the power main equally and modulates the current drawn from the power supply 10 in a controlled and incremental rate to provide power to the means for heating a workpiece 46. This type of control allows for precise control of the temperature of the workpiece 26.

The power source controller 12 also includes a temperature control unit 48 which is connected to means for sensing temperature of the workpiece 50 via sensing line 52. Although the means for sensing temperature 50 is illustrated as a thermocouple, any suitable means for sensing the temperature of a workpiece can be used, if so desired. The temperature control unit 48 is also connected to the heating power supply 40 via heating power supply line 54. The temperature control unit 48 controls the provision of power to the means for heating the workpiece 46 in conformance with a programmed temperature profile and in response to the means for sensing the temperature 50. If the temperature of the workpiece falls below a programmed value, the means for sensing the temperature 50 responds to this condition and the temperature control unit 48 signals the heating power source 40 to provide additional output to the means for heating the workpiece 26, thereby raising the temperature of the workpiece 26. On the other hand, if the temperature of the workpiece 26 exceeds a predetermined value, the means for sensing temperature 50 senses this condition and the temperature control unit 48 signals the heating power source 40 to provide less output to the means for heating the workpiece 46.

A unique feature of the temperature control unit 48 is the precise control of power output by the heating power source 40 through incremental modulation of the output amperage. This feature regulates changes in the heating power source output to respond smoothly and slowly to commands from the temperature control unit 48 so as to avoid any sudden change in demand on the power supply 10 which would otherwise adversely effect control of the welding power source 16 or other electrical equipment supplied by the same power supply 10.

Also included in the power source controller 12 is a power monitor 56 and a power control unit 58. The power monitor 56 is connected to the second multi-pin port 36 and monitors the power demand of the welding power source 16. The power monitor 56 is also connected to the power control unit 58 which, in turn, is connected to the heating power source 40.

A central control microprocessor 60 within the power source controller 12 accomplishes the operational interactivity of the present invention apparatus. The central control microprocessor 60 is connected to all of the other components of the power source controller 12. As illustrated in FIG. 2, the central control microprocessor 60 interactively coordinates the functions of these components to facilitate continuous precision welding. Predetermined values for a welding procedure are entered into the central control microprocessor. In a preferred embodiment, entered data typically includes, but is not limited to,: (1) weld tag number; (2) line, vessel or workpiece identification; (3) location and name of the plant where the operation is being performed; (4) welding engineer, the weld operator and weld inspector; (5) minimum preheat temperature; (6) optimum preheat temperature; (7) minimum interpass temperature; (8) optimum low interpass temperature; (9) optimum high interpass temperature; (10) maximum allowable interpass temperature; (11) voltage and/or amperage settings; (12) lower interpass alarm temperature; (13) upper interpass alarm temperature; (14) voltage/amperage adjustment rate as a function of interpass temperature; (15) post weld heat treatment (PWHT) initial ramp rate; (16) PWHT initial temperature set-point; (16) secondary PWHT ramp rate; (17) PWHT soak temperature; (18) PWHT soak time; (19) PWHT temperature fall rate; and (20) PWHT final control temperature.

Variations in arc voltage and current will invariably occur due to movements of the welding torch 22 by the welding operator, variations in the workpiece surface, and the action of the molten metal dropping into the weld pool. The welding power source 16 responds to such variations and continuously adjusts actual output power to the means for producing an electrical arc to maintain preset values. Additionally, the central control microprocessor 60 constantly monitors the power demand and supply of the heating power source 40 of the power source controller 12 and the welding power source 16 such that it can provide power from the power supply 10 to one or both, individually, or simultaneously, in response to input from the heating power source 40, the welding power source 16, the temperature control unit 48, the power monitor 56, the power control unit 58 and preprogrammed welding operational parameters and workpiece operational parameters. The power control unit 58 in the power source controller 12, in response to a signal from the central control microprocessor 60, limits the amount of power which can be diverted from the welding power source 16 to the heating power source 40 of the power source controller 12 to prevent any disruption of the welding arc control by the welding power source 16. Power which is diverted to the heating power supply 40 is converted to a higher amperage, lower voltage alternating current suitable for resistance heating.

The welding operational parameters are ideally monitored by the central control microprocessor 60 at a frequency of at least once per second and as fast as twenty (20) times per second. The actual frequency selected will depend upon welding procedure-specific considerations. At a high frequency of such data monitoring and acquisition, the power source controller 12 is utilized to monitor the skill and technique of the weld operator in controlling the torch and weld pool utilizing different weld processes in different weld positions.

The central control system 60 can be programmed to automatically change the voltage/amperage controls 31 of the welding power source 16 in response to changes in the monitored temperature of the workpiece 26. In practice, the energy of the arc may well add sufficient heat to the workpiece 26 so as to cause the workpiece temperature to climb toward the upper interpass temperature deviation limit

during the welding operation. This phenomena will typically occur when the relative energy of the arc is high compared to the mass and natural rate of heat dissipation of the workpiece 26. In such cases the power source controller 12 gradually reduces power to the heating power source 40 to counteract the undesired rise in temperature. At the election of the welding operator or engineer, the central control unit 60 can be programmed to begin to slowly reduce the output power from the welding power source 16 should the workpiece temperature continue to rise. This unique feature of the present invention is preferable to manually resetting the welding power source 16 output. Small incremental reductions in output power to the welding torch 22 by the present invention as a function of workpiece temperature assists the welding operator in maintaining control of the weld pool size and shape and prevents excessive splattering due to excessive heat and arc energy. This feature is especially useful on small workpieces or on workpieces of aluminum or similar alloys which often are prone to increased weld pool size due to increasing workpiece temperatures as a result of the welding operation. This feature also facilitates the quick start of a welding operation by providing a boost of power immediately upon striking the welding torch 22. Once the welding operation begins, the output automatically can be decreased to normal operational levels.

The central control microprocessor 60 can also be programmed to cause the temperature control unit 48 to regulate the healing power source 40 output to follow a post-weld heat treating program as prescribed by regulatory codes and recommended practices. Since such post weld heat treatments are performed only after completion of the welding operation, the central control unit 60 directs the power control unit 58 to divert all available input power to the heating power source 40 once actual welding operations are concluded. The temperature control unit 48 modulates the output current of the heating power source 40 to cause the monitored workpiece temperature to follow the preprogrammed temperature set-point. A unique capability of the present invention apparatus is the ability to disconnect the welding power source 16 from the power source controller 12 prior to or during a post weld heat treatment to allow the welding power source 16 to be utilized for other welding operations without affecting the ability of the power source controller 12 to complete the post weld heat treatment.

Another feature of the power source controller 12 is the ability of the unit to start the preheat of the workpiece 26 at a preset time. In a preferred embodiment the central control microprocessor 60 is equipped with a real time clock (not shown). In use, the welding operator or welding engineer presets the power source controller 12 to begin preheating the workpiece 26 at a predetermined time. This feature allows a workpiece 26 to be at the required preheat temperature at the start of a work shift, for example.

The central control microprocessor 60 also includes: a display 62 for the visual presentation of data, a keypad 63 for entry of data, and means for acquiring and storing data 64 for real time acquisition of welding operational parameters, workpiece operational parameters and other data. Acquired or calculated data typically includes, but is not limited to,: (1) actual welding output voltage vs. time; (2) actual welding output amperage vs. time; (3) workpiece temperature vs. time; (4) voltage/current settings vs. time; (5) actual heating supply output voltage and amperage vs. time; (6) preheat start time; (7) time at which workpiece achieved minimum preheat temperature; (8) welding operation initiation; (9) welding operations completion; (10) total elapsed welding time; (11) total elapsed arc time; (12) total number of arc starts; (13) initiation of PWHT; and (14) PWHT completion. The result is a complete log of welding operational parameters, workpiece operational parameters, and other weld identification information for subsequent use and/or output. Data is stored by the means for acquiring and storing data 64 on any suitable data storage medium, such as magnetic tape or computer disk. Additionally, a data output module 66 directs data acquired and stored during a welding operation to a printer, plotter, chart recorder or like device, if a hard copy of the welding log is desired.

Means for producing an alarm 68 is also within the power source controller 12. Like the foregoing components of the power source controller 12, the means for producing an alarm is connected to the central control microprocessor 60. The means for producing an alarm 68 produces a visual and/or audible alert when attempts at welding occur outside a predetermined range of deviation from a preprogrammed optimum interpass temperature.

Specifically, the central control microprocessor 60 receives a signal from the power control unit 58 that the power welding source 16 is drawing power at a time when the means for sensing the temperature 50 senses that the temperature of the workpiece 26 is outside a first predetermined deviation range from a preprogrammed optimum interpass temperature. The central control microprocessor 60 signals the means for producing an alarm 68 so that an audible and/or visual alarm will be presented to the welding operator. This alarm allows the welder to adjust his or her technique and/or the settings of the welding power source to bring the welding conditions back into the acceptable range of deviation from the preprogrammed optimum interpass temperature before additional attempts at welding occur.

Additionally, the central control microprocessor 60 will signal the power control unit 58 to temporarily prevent output of power from the welding power source 16 to the welding torch 22 in the event attempts at welding occur outside a second predetermined range of deviation from the preprogrammed optimum interpass temperature.

Remote port 70 on the power source controller 12 and remote line 72 allow contemporaneous feedback of welding operational parameters and workpiece operational parameters and presentation of alarms to a welding operator at a location remote from the power source controller 12. A remote keypad 74 allows a welding operator to enter data such as weld identification information, such as weld tag number, name, identification number, date, location, etc., into the central control microprocessor 60 of the power source controller 12. Such data is acquired and stored by the means for acquiring and storing data 64, along with the welding operational parameters and workpiece operation parameters for the welding procedure. Although the remote keypad 74 illustrated is hard-wired to the power source controller 12, the remote keypad could also send data to the power source controller 12 via wireless transmission, if so desired.

Although the present invention apparatus has been illustrated using a stick arc welding operation, the invention would facilitate other arc welding applications including but not limited to, gas tungsten arc welding and metal inert gas welding.

A preferred method of the present invention is illustrated in FIG. 3, wherein there is shown a flow diagram of the steps. Initially, a weld procedure is assigned for a welding operation 100. Typically, as mentioned previously herein, such procedures are required, or at least recommended, by

laws or professional standards coveting a particular weld operation. Next, optimum welding operational parameters and workpiece operational parameters for said procedure are entered into an apparatus for facilitating precision welding 120. Typically parameters include, but are not limited to: (1) minimum preheat temperature necessary to activate output power from the welding operation power source; (2) maximum preheat temperature above which the welding power source output will be deactivated; (3) target interpass temperature; (4) a first range of temperature deviation above or below which an alarm is triggered; (5) a second range of temperature deviation above or below which welding operation power source output is temporarily interrupted; (6) welding operation power source output settings, including voltage and current; (7) welding electrode size and type, or filler metal wire size and feed rates; and (8) welding operation power source output rate(s) of change as a function of workpiece temperatures.

Once these parameters are preset, the parameters are evaluated through actual welding operation on a test specimen or test area to ensure that such preset parameters perform the weld procedure assigned 130. If the desired results are not obtained using the preset parameters, one or more of the parameters will be modified and steps 120 and 130 are repeated until step 130 indicates that the preset parameters produce the desired weld quality. The performance of one or more welding operators in step 130 is reviewed by a welding engineer or the quality control inspector to determine whether additional reiterations of steps 120 and 130 are needed.

Additionally, during step 130 one or more welding operators can be qualified for the desired welding procedure (i.e., determine whether they can perform the desired welding procedure), reducing or eliminating the need for expensive and time-consuming destructive testing of weld test coupons. Training of welding operators can also occur during step 130, if so desired. Under such circumstances, the weld operator would be given contemporaneous feedback and/or shown a record of his or her attempt(s) to adhere to the assigned welding procedure. If needed, the weld operator would be given instruction and tips on how to improve his or her technique, as well as the opportunity for additional practice.

Once the preset parameters have been finalized and one or more weld operators have been qualified as capable of meeting the performance criteria of the assigned weld procedure, actual production of the defined precision welding procedure on an actual production workpiece is then accomplished (140). Step 140 includes welding operator(s) interactively welding on the workpiece(s) in response to contemporaneous feedback of welding operational parameters, workpiece operational parameters, alarms and temporary interruptions of the welding procedure. As previously described, attempts at welding outside a first predetermined temperature deviation from the optimum parameters are identified audibly or visually to the welding operator so that minute modifications in settings, form, etc. can be accomplished. Attempts at welding outside a second predetermined range of temperature deviation from the optimum parameters result in a temporary interruption of power to the welding arc, thus preventing welding until the optimum temperature range is regained.

Occurring simultaneously with step 140 is step 150, wherein a weld record is acquired on a real time basis and compiled by acquiring and storing a complete log of the welding operational parameters and workpiece operational parameters during the welding operation.

Upon successful completion of steps 140 and 150, the welding engineer or quality control inspector evaluates the completed weld by reviewing the weld record 160. Evaluation of the weld record plays a key role in determining whether to proceed immediately with post weld heat treatment before proceeding with the NDT inspection. The ability to proceed directly from the weld operation into PWHT can save valuable time and expense when the workpiece operation dictates that a relatively high interpass temperature is required. Under such circumstances the workpiece power source can be programmed to raise the workpiece temperatures in a controlled fashion as prescribed by the applicable codes and recommended practices starting from the elevated interpass temperature without first allowing the workpiece to cool to perform NDT testing only to subsequently be required to re-heat the workpiece as part of the PWHT procedure.

Additional uses for the compete weld record include, but are not limited to: (1) providing assurance that the desired weld procedures were properly and consistently implemented; (2) assisting in defining appropriate weld and workpiece operations for future work on the same or similar workpieces; (3) training welding operators; (4) evaluating the performance of welding operators; (4) evaluating the cause of a weld joint's failure of NDT inspection; and (5) facilitating temperbead welding.

Only the preferred embodiments of the invention have been described. It should be understood that the invention is not limited to the embodiments disclosed, but is intended to embrace any alternative, modification, rearrangements, or substitutes of parts or elements as fall within the spirit and scope of the invention.

We claim:

1. An apparatus to facilitate the consistent performance of precision welding, comprising:

a power source;

a power source controller;

means for producing an electric arc;

means for heating a workpiece;

means for sensing temperature of the workpiece;

said power source controller controlling the power source to interactively provide power output to the means for producing an electric arc and to the means for heating a workpiece in response to input from the means for heating the workpiece, input from the means for sensing the temperature of the workpiece, input from the means for producing an electric arc, and predetermined welding operational parameters.

2. The apparatus of claim 1, wherein the power source controller includes a power monitor and an interactive control microprocessor to monitor power demand and supply of the means for producing an electric arc and power demand and supply of the means for heating a workpiece and to control interactive provision of power by the power source to the means for producing an electric arc and the means for heating a workpiece in response thereto.

3. The apparatus of claim 1, wherein the power source controller prevents output of the power source to the means for producing an electric arc until the means for sensing temperature of the workpiece detects a predetermined minimum temperature value.

4. The apparatus of claim 1, wherein the power source controller controls power output of the power source to the means for heating a workpiece in response to input from the means for sensing temperature of the workpiece to maintain a predetermined optimum interpass temperature.

5. The apparatus of claim 4, wherein the power source controller further includes means for producing an alarm when demand from the means for producing an electric arc occurs above or below a first predetermined range of deviation from the predetermined optimum interpass temperature.

6. The apparatus of claim 5, wherein the alarm produced is visual.

7. The apparatus of claim 5, wherein the alarm produced is auditory.

8. The apparatus of claim 1, wherein the means for heating a workpiece includes resistance heating.

9. The apparatus of claim 1, wherein the means for heating a workpiece includes induction heating.

10. The apparatus of claim 1, wherein the means for heating a workpiece includes radiant heating.

11. The apparatus of claim 1, wherein the power source controller further includes means for temporarily interrupting power output from the power source to the means for producing an electric arc when demand from the means for producing an electric arc occurs above or below a second predetermined range of deviation from the predetermined optimum interpass temperature.

12. The apparatus of claim 1, wherein the power source further includes means for automatically modulating the output power of the means for producing an electric arc in response to deviations from a predetermined range of temperatures of the workpiece.

13. The apparatus of claim 12, wherein the means for automatically modulating the output power of the power source to the means for producing an electric arc modulates said output power at a programmed rate.

14. The apparatus of claim 1, wherein the means for sensing the temperature of the workpiece is a bimetallic thermocouple.

15. The apparatus of claim 1, wherein the means for temperature of the workpiece includes a radiant energy measurement device.

16. The apparatus of claim 1, wherein the means for producing an electric arc is a conventional thyristor design.

17. The apparatus of claim 1, further including means for monitoring and displaying welding operational parameters and workpiece operation parameters.

18. The apparatus of claim 1, wherein welding operational parameters are monitored at a frequency of at least once per second.

19. The apparatus of claim 1, further including means for electronically acquiring and storing the welding operational parameters and workpiece operational parameters monitored during welding operations for subsequent retrieval and display.

20. The apparatus of claim 19, wherein the means for electronically acquiring and storing welding operational parameters and workpiece operational parameters further includes clock means for referencing a sequence of data acquisition.

21. The apparatus of claim 1, further including means for displaying the welding operational parameters and workpiece operational parameters monitored during welding operations.

22. The apparatus of claim 19, wherein the means for electronically storing welding operational parameters and workpiece operational parameters is a magnetic tape.

23. The apparatus of claim 19, wherein the means for electronically storing welding operational parameters and workpiece operational parameters is a memory disk.

24. The apparatus of claim 21, wherein the welding operational parameters and workpiece operational parameters acquired and stored are outputted to a printer, plotter or chart recorder.

25. The apparatus of claim 21, wherein the welding operational parameters and workpiece operational parameters acquired and stored are outputted to a screen display.

26. The apparatus of claim 21, wherein the welding operation parameters and workpiece operational parameters acquired and stored are outputted to a computer disk.

27. The apparatus of claim 1, further including means for providing to an operator of the apparatus contemporaneous feedback of welding operational parameters and workpiece operational parameters and alarm status during welding operation.

28. The apparatus of claim 27, wherein the contemporaneous feedback is auditory.

29. The apparatus of claim 27, wherein the contemporaneous feedback is visual.

30. The apparatus of claim 27, wherein the means for providing contemporaneous feedback to the operator of the apparatus further includes means for providing said contemporaneous feedback to a location remote from the apparatus.

31. The apparatus of claim 30, wherein the means for remote provision of contemporaneous feedback includes wired transmission.

32. The apparatus of claim 30, wherein the means for remote provision of contemporaneous feedback includes wireless transmission.

33. The apparatus of claim 30, wherein the means for remote provision of contemporaneous feedback includes a keypad for input of data with the power source controller from the remote location.

34. The apparatus of claim 33, wherein the data input with the power source controller includes weld identification information.

35. The apparatus of claim 34, further including means to prevent welding operations from occurring if the weld identification entered into the power source controller does not match predetermined values for a particular weld operation.

36. An apparatus to facilitate the consistent performance of precision welding, comprising:

a power source;

a power source controller;

means for producing an electric arc;

means for heating a workpiece;

means for sensing temperature of the workpiece;

said power source controller including a monitor and interactive control circuitry to monitor power demand and supply of the means for producing an electric arc and power demand and supply of the means for heating a workpiece;

said power source controller further including means for producing an alarm when demand from the means for producing an electric arc occurs above or below a first predetermined range of deviation from a predetermined optimum interpass temperature;

said power source controller further including means for temporarily interrupting power output from the power source to the means for producing an electric arc when demand from the means for producing an electric arc occurs above or below a second predetermined range of deviation from the predetermined optimum interpass temperature;

said power source controller further including means for automatically adjusting output of the power source in response to deviations in the temperature of the workpiece as sensed by the means for sensing temperature of the workpiece;

means for electronically acquiring and storing welding operational parameters and workpiece operational parameters monitored during welding operations for subsequent retrieval and display;

means for providing to an operator of the apparatus contemporaneous feedback of welding operational parameters and workpiece operational parameter and alarm status during welding operation; and

means for data input to the power source controller;

said power source controller controlling the power source to interactively provide power output to the means for producing an electric arc and to the means for heating a workpiece in response to input from the means for heating the workpiece, input from the means for sensing the temperature of the workpiece, input from the means for producing an electric arc, input from the means for data input, means for automatically adjusting output of the power source in response to deviations in the temperature of the workpiece,

and predetermined welding operational parameters.

37. An apparatus for heat treatment of a workpiece powered from a power main having other electrical equipment drawing power from said power main, comprising:

a power source;

a power source controller;

means for heating a workpiece;

means for sensing temperature of the workpiece;

said power source controller modulating power output to the means for heating a workpiece in response to input from the means for heating the workpiece, input from the means for sensing the temperature of the workpiece and predetermined workpiece operational parameters; and

said power source controller capable of modulating power output to the means for heating a workpiece without interfering with supply of power to additional electrical equipment powered by said power main.

38. The apparatus of claim 37, wherein the power source draws on all three phases of said power main equally.

39. The apparatus of claim 37, wherein the power source provides alternating current output to the means for heating a workpiece.

40. The apparatus of claim 37, wherein the power source controller modulates amperage output of the power source.

41. The apparatus of claim 40, wherein modulation of the amperage output of the power source is at a controlled and incremental rate.

42. The apparatus of claim 37, wherein the power source controller automatically adjusts the output power of the power source in response to deviations in the temperature of the workpiece.

43. The apparatus of claim 42, power source controller automatically adjusts the output power of the power source in response to deviations in the temperature of the workpiece at a programmable controlled and incremental rate.

44. The apparatus of claim 37, further including means for electronically acquiring and storing the workpiece operational parameters monitored during workpiece operations for subsequent retrieval and display.

45. The apparatus of claim 44, wherein the means for electronically acquiring and storing workpiece operational parameters further includes clock means for referencing a sequence of data acquisition.

46. The apparatus of claim 37, further including means for displaying the workpiece operational parameters acquired and stored during workpiece operations.



47. The apparatus of claim 44, wherein the means for electronically storing workpiece operational parameters is a magnetic tape.

48. The apparatus of claim 44, wherein the means for electronically storing workpiece operational parameters is a computer disk.

49. The apparatus of claim 46, wherein the workpiece operational parameters acquired and stored are outputted to a printer, plotter or chart recorder.

50. The apparatus of claim 37, further including means for providing to an operator of the apparatus contemporaneous feedback of workpiece operational parameters during workpiece operations.

51. The apparatus of claim 37, wherein output from the means for heating a workpiece is varied by incrementally increasing or decreasing the amperage output provided to the means for heating a workpiece.

52. A method to facilitate consistent precision arc welding operations, comprising the steps of:

assigning a weld procedure for a welding operation;

entering optimum welding operational parameters and workpiece operational parameters for said procedure into an apparatus for facilitating precision welding;

interactively welding in response to contemporaneous feedback of welding operational parameters, temporary interruption of the welding operation, workpiece operational parameters and alarms; and

acquiring and storing a log of welding operational parameters.

53. The method of claim 52, further including the step of displaying the welding operational parameters and workpiece operational parameters.

54. The method of claim 52, further including the step of programming interactive output from a means for producing an electric arc as a function of the temperature of the workpiece.

55. A method of evaluating performance of a welding operator, comprising the steps of:

assigning a weld procedure for a welding operation to evaluate performance of the welding operator;

entering optimum welding operational parameters and workpiece operational parameters for said procedure into an apparatus for facilitating precision welding;

causing the welding operator to interactively weld in response to contemporaneous feedback of welding operational parameters, temporary interruption of the welding operation, workpiece operational parameters, and alarms;

acquiring and storing a log of welding operational parameters; and

comparing the log of welding operational parameters recorded to the assigned weld procedure to evaluate the performance of the welding operator.

56. A method of training welding operators, comprising the steps of:

assigning a weld procedure for a welding operation;

entering optimum welding operational parameters and workpiece operational parameters for said procedure into an apparatus for facilitating precision welding;

causing one or more welding operators to interactively weld in response to contemporaneous feedback of welding operational parameters, temporary interruption of the welding operation, workpiece operational parameters, and alarms;

acquiring and storing a log of welding operational parameters; and

displaying the log of welding operational parameters acquired and stored and the assigned weld procedure to train the welding operators.

57. A method of ensuring compliance with mandated or recommended weld practices and procedures, comprising the steps of:

assigning a mandated or recommended weld procedure for a welding operation;

entering optimum welding operational parameters and workpiece operational parameters for said procedure into an apparatus for facilitating precision welding;

interactively welding in response to contemporaneous feedback of welding operational parameters, temporary interruption of the welding operation, workpiece operational parameters, and alarms;

acquiring and storing a log of welding operational parameters; and

comparing the log of welding operational parameters recorded to the required weld procedure to verify compliance with the procedure.

58. A method of determining the cause of a weld joint to fail NDT inspection, comprising the steps of:

assigning a required weld procedure for a welding operation;

entering optimum welding operational parameters and workpiece operational parameters for said procedure into an apparatus for facilitating precision welding;

interactively welding in response to contemporaneous feedback of welding operational parameters, temporary interruption of the welding operation, workpiece operational parameters, and alarms;

acquiring and storing a log of welding operational parameters and workpiece operational parameters; and

examining the log of welding operational parameters and workpiece operational parameters acquired and stored to determine cause of welded joint to fail NDT inspection.

59. The method of claim 58, further including step of examining the log of welding operational parameters and workpiece operational parameters acquired and stored to determine the potential for a weld joint to fail NDT inspection.

60. A method of determining whether immediate post weld treatment of a weld is feasible without the need for cooling and/or examining the workpiece, comprising the steps of:

assigning a weld procedure for a welding operation;

entering optimum welding operational parameters and workpiece operational parameters for said procedure into an apparatus for facilitating precision welding;

interactively welding in response to contemporaneous feedback of welding operational parameters, temporary interruption of the welding operation, workpiece operational parameters, and alarms;

acquiring and storing a log of welding operational parameters and workpiece operational parameters; and

examining the log of welding operational parameters and workpiece operational parameters acquired and stored to determine cause of welded joint to fail NDT inspection.

61. A method for eliminating the need for post weld heat treatment for a welding operation, comprising the steps of:

assigning a temperbead weld procedure for a welding operation;

entering optimum welding operational parameters and workpiece operational parameters for said procedure into an apparatus for facilitating precision welding;

interactively welding in response to contemporaneous feedback of welding operational parameters, temporary, interruption of the welding operation, workpiece operational parameters, and alarms;

acquiring and storing a log of welding operational parameters and workpiece operational parameters; and

examining the log of welding operational parameters and workpiece operational parameters acquired and stored to confirm effectiveness of said procedure.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

# CERTIFICATE OF CORRECTION



PATENT NO. : 5,708,253

DATED : Jan. 13, 1998

INVENTOR(S) : Bloch et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

| | |
|---|---|
| Column 1, line 55 | Replace "method"<br>With --methods-- |
| Column 2, line 10 | Replace "are"<br>With --arc-- |
| Column 2, line 65 | Replace "are"<br>With --arc-- |
| Column 4, line 51 | Replace "requiting"<br>With --requiring-- |
| Column 5, line 44 | Replace "an"<br>With --art-- |
| Column 9, line 28 | Replace "healing"<br>With --heating-- |
| Column 11, line 1 | Replace "coveting"<br>With --covering-- |

UNITED STATES PATENT AND TRADEMARK OFFICE
# CERTIFICATE OF CORRECTION



PATENT NO. : 5,708,253

DATED : Jan. 13, 1998

INVENTOR(S) : Bloch et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

| | |
|---|---|
| Column 16, line 18 | Replace "are" With --arc-- |
| Abstract, Item [57], line 2 | Replace "are" With --arc-- |

Signed and Sealed this

Fifth Day of January, 1999

Attest:

Q. Todd Dickinson

Attesting Officer

*Acting Commissioner of Patents and Trademarks*

US-PAT-NO: 5185513

DOCUMENT-IDENTIFIER: US 5185513 A

TITLE: Heat controller and method for heat treatment of metal

---------- KWIC ---------

Detailed Description Text - DETX (12):
In an alternative embodiment (not shown), the temperature sensor/controller, or comparator, 34 is replaced by a programmable timer. Such a programmable means allows the operator to begin operations at a predetermined time to heat metal to a desired temperature at a desired rate, both the desired temperature and the rate of heating (e.g., percentage power) being predetermined and programmed into such a device, as well as the time of commencement of operations. Regardless of whether a programmable means is provided, the present invention optionally contemplates the use of a chart **recorder** for monitoring the **temperature** of the metal, lapsed time of operation, and/or the duty cycle of applications power supply 22 as a function of time as known in the art.

Claims Text - CLTX (9):
4. The apparatus of claim 1 additionally comprising means for **recording** the duty cycle of the applications power supply or the

US005185513A

# United States Patent [19]

**Pacileo**

[11] **Patent Number: 5,185,513**

[45] **Date of Patent: Feb. 9, 1993**

[54] **HEAT CONTROLLER AND METHOD FOR HEAT TREATMENT OF METAL**

[75] Inventor: Stephen P. Pacileo, Friendswood, Tex.

[73] Assignee: PR Partners, Pasadena, Tex.

[21] Appl. No.: 497,436

[22] Filed: Mar. 22, 1990

[51] Int. Cl.[5] ........ H05B 1/02

[52] U.S. Cl. ........ 219/497; 219/505; 219/549; 219/535; 219/494; 228/231; 228/119; 228/232

[58] Field of Search ........ 219/50, 550, 497, 494, 219/501, 505, 506, 535, 508, 549; 228/119, 231, 232

[56] **References Cited**

U.S. PATENT DOCUMENTS

| | | | |
|---|---|---|---|
| 3,036,187 | 5/1962 | Goldstaub et al. | 219/550 |
| 3,851,148 | 11/1974 | Schonert et al. | 219/497 |
| 4,611,744 | 9/1986 | Fraser et al. | 228/119 |
| 4,613,744 | 9/1986 | Fraser | 219/550 |
| 4,701,589 | 10/1987 | Larsson | 219/50 |

OTHER PUBLICATIONS

Cooperheat Technical Information (Exerpts) May, 1972.

Kemppi Classics Advertising Brochure (date unknown).

Kemppi PS 3500/PS 5500 Inverter Power Supplies—Advertising Brochure (date unknown).

Kemppi PS 2800 Inverter Power Supply-Advertising Brochure (date unknown).

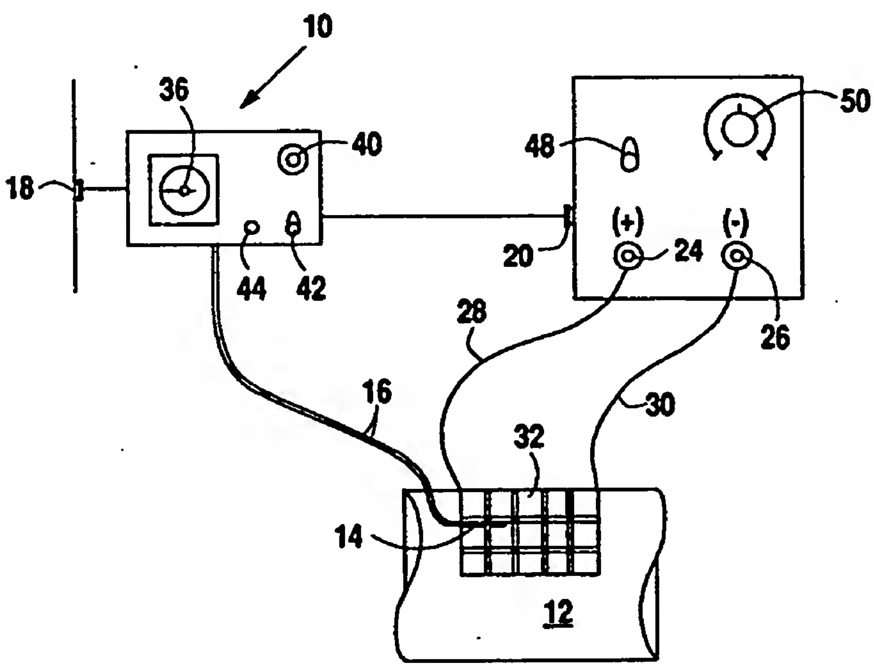
*Primary Examiner*—Mark H. Paschall

*Attorney, Agent, or Firm*—Vaden, Eickenroht, Thompson, Boulware & Feather

[57] **ABSTRACT**

Method and apparatus for increasing the efficiency and safety of conducting heat treating operations with conventional welding equipment by eliminating mechanically-operated contacters. The apparatus operates on low power and produces low power level signals and controls power sources capable of producing high power levels for both welding operations and powering a heating element for heat treatment. The signal produced by the apparatus reflects a difference between an operator-selected desired temperature and the actual temperature of the workpiece and is current limited to a level proportional to the operator-selected desired power level of the welding power source to control the rate at which the heating element connected thereto heats the workpiece.

**20 Claims, 1 Drawing Sheet**



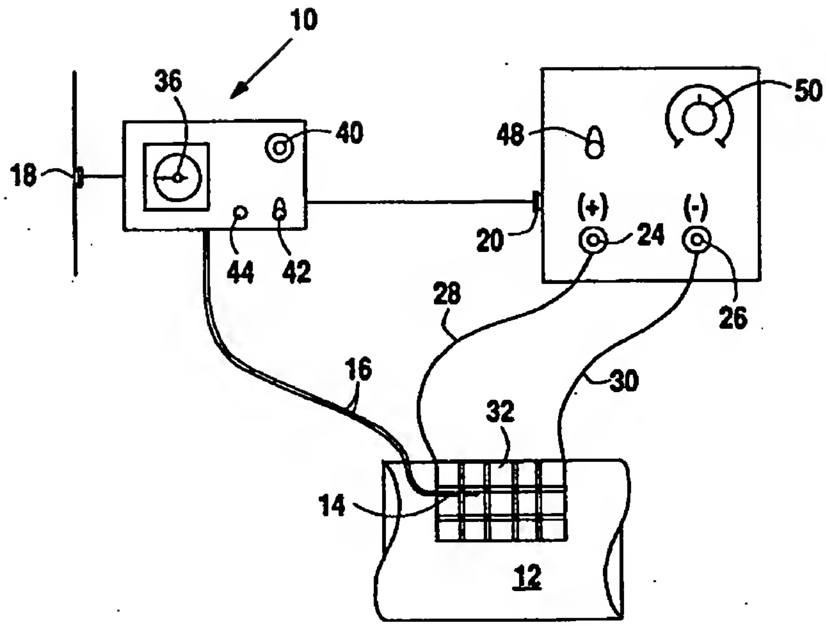

10
36
40
50
48
18
(+)
(-)
20
24
44
42
26
28
16
30
32
14
12

Fig. 1

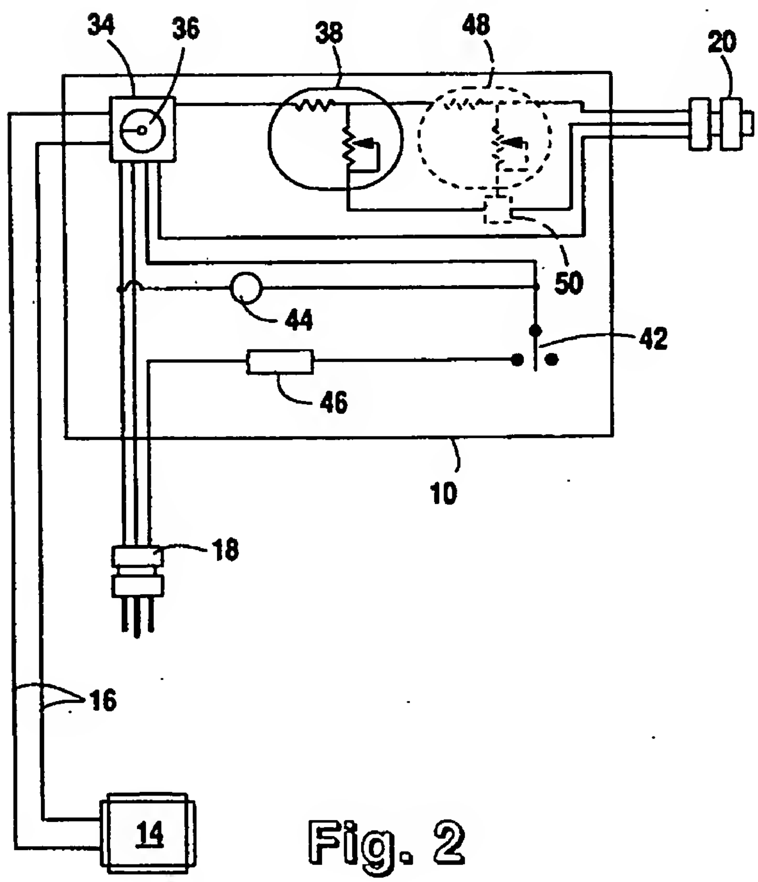

34
36
38
48
20
50
44
42
46
10
18
16
14

Fig. 2

# HEAT CONTROLLER AND METHOD FOR HEAT TREATMENT OF METAL

## BACKGROUND OF THE INVENTION

The present invention relates to an apparatus and method for controlling the heating of metal such as for pre-weld or post-weld heat treatment, stress relief, or for controlling the heating of metallic conduits and containers to prevent the freezing and improve the fluidity of materials contained therein. In more detail, the present invention relates to an apparatus which controls an applications power supply for heating a workpiece to a desired temperature at a desired rate without passing the power produced by that power supply through that apparatus as well as a method of controlling that power supply to achieve that same result.

The importance of heating metal before, during, and-/or after welding is well documented. Preheating, a term used to describe heating both prior to and during welding, helps prevent the terminal strains set up during welding that can crack the weld, protects against the high thermal conductivity of, for instance, relatively thick carbon steel which causes heat loss from the welded area, increases the diffusion rate of crack-promoting hydrogen, facilitates removal of hydrogen from a welded joint, and drives off harmful moisture. Post-heating, or post-weld heat treatment, relieves residual stresses in the weld due to the restraint by the parent metal during weld solidification to provide increased ductility in the weld metal and a decrease in hardness, improves corrosion resistance and resistance to caustic embrittlement, and improves machining stability. Recognition of the importance of heat treating throughout the metal-working and fabrication industry has given rise to a whole industry in which companies specializing in heat treatment render, for instance, on-site heat treating services on a contract basis during, for instance, the construction of bridges, refineries, nuclear reactors, and other structures which must be welded.

In spite of the availability of these contract services and the recognized importance of heat treatment, there remains a large number of welds that are not heated, pre- or post-weld, or which are not effectively heat treated, because of the cost of such treatment, a lack of necessary equipment, or because such treatment is deemed unnecessary because the metal joint has been "over-engineered", e.g., made of metals that are so much stronger/durable than is required by the particular application that they are strong enough to meet specifications even after they are weakened by the weld. It is to these latter wasteful efforts that the present invention is directed in that an apparatus and method are provided that are so relatively inexpensive to purchase and easy to operate that heat treatment is brought within the means and capabilities of any legitimate welder and/or fabricator.

Another goal of the present invention is to provide an apparatus for use in heat treatment that operates in conjunction with the equipment which is commonly used for welding and/or heat treating metals.

Another goal of the present invention is to provide a method of using the equipment which is commonly used for welding and/or heat treating metal.

Another goal of the present invention is to provide an apparatus and method by which the rate at which the metal is heated is controlled, again with commonly used welding equipment.

Another goal of the present invention is to provide an apparatus for heating metal which is light in weight and small, thereby facilitating the transport of the apparatus.

Another goal of the present invention is to provide an apparatus and method for use in conjunction with the equipment commonly used for welding and/or heat treating metals which controls the power output of such equipment at two selected power levels for pulsed operation.

Another goal of the present invention is to provide an apparatus and method for controlling the heating of metal to prevent freezing or improve the fluidity of materials contained within a metallic component such as a tank or pipeline.

A particularly important goal of the present invention is to provide a method and apparatus by which a metallic workpiece is heated to a desired temperature at a desired rate without passing the power used to heat the workpiece through the circuitry used for controlling the power supply, thereby increasing the safety of that equipment.

Other goals, and the advantages, of the present invention will be made clear by the following description of a presently preferred embodiment thereof.

## SUMMARY OF THE INVENTION

In a first aspect, the present invention is directed to an apparatus for controlling the heating of a metallic workpiece to a desired temperature comprising a means for sensing the temperature of the metallic workpiece that outputs a signal proportional to that temperature, a first connector for receiving input power from an external power source, and means operating on the power received from that first connector for receiving the output signal from the temperature sensing means and outputting a signal responsive to the difference between a desired temperature, which is operator selected, and the temperature sensed by the sensing means. That difference signal is used to turn an applications power supply, e.g., a rectifier, inverter, or other power source, for powering a heating element, on and off. Means is provided for limiting the current of the difference signal that outputs a current limited signal proportional to the desired power level, also operator selected, of the applications power supply to control the rate of heating of the metallic workpiece by the heating element, the current limited signal being transmitted to the applications power supply by a second connector.

In another aspect, the present invention is a method for controlling the heating of a metallic workpiece to a desired temperature comprising the steps of selecting a temperature to which it is desired to heat the workpiece, sensing the temperature of the workpiece, and comparing the sensed temperature of the workpiece to the desired temperature. If the sensed temperature is greater than the desired temperature, a signal is output and then current limited so that the current level is proportional to the desired power level of an applications power supply. The current limited output signal is then output to the applications power supply to switch the applications power supply on to heat the workpiece.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts a representative system including the apparatus of the present invention.

FIG. 2 is a schematic diagram of a presently preferred embodiment of an apparatus constructed in accordance with the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Welding operations require a fairly healthy capital investment in equipment, and the equipment required for even modest welding capabilities is fairly substantial in size, and especially in weight, which therefore necessitates additional investment in transport equipment. Even with the relatively recent widespread availability of reliable and efficient light-weight power inverters, on-site welding requires a power source such as a gasoline or diesel powered generator, a rectifier or inverter, various control equipment depending upon the type of welding, cables, and so on. If the welder also expects to heat treat, various finger elements, ceramic pad heaters, braided heaters, or other heating elements, connectors, control boxes, cables and, in many cases, power sources, may also be required.

It is now fairly common to use a common power supply, operating off of a generator, to supply power for both heat treating and actual welding operations (hence, the use of the phrase "applications power supply" throughout this specification) such that at least some duplication in equipment has been eliminated. However, regardless of whether the applications power supply is used for heat treatment or welding, it is generally considered to produce power at levels sufficient to be considered dangerous if not used properly even at relatively modest output capabilities. The power levels required for welding (e.g., from as few as about 2-5 amperes at about 10 volts up to as high as several thousand, or even 10,000, amperes at, for instance, 80 volts for certain types of welding) and heavy loads which the various types of resistive heaters used for heat treatment present to the applications power supply require that the applications power supply be a source of what can be termed "high power" for the purposes of this specification. These high power sources are, of course, part of a circuit when used for heat treating, and turning them on and off to control the temperature to and the rate at which the workpiece is heated requires a switch which opens or closes the circuit through which that high power current is routed.

Such switches are contained in a controller, many of which can be characterized as a metal box in which a contacter is located for closing the circuit to the welding tip and/or heating element. These contacters are generally considered to be the weakest link in the circuit because they are the most likely part of the circuit to fail. They are necessarily large (to handle, for instance, 80 volts at 500 amperes, they must be) and one pole is always "live". It is not uncommon for the live contacter to ground out against the metal control box; another relatively common occurance, when a contacter fails, is that the contacter fuses closed such that there is no way to turn the circuit off.

Adding to these difficulties with such equipment is the fact that the control box, having the contacter located therein, represents a spark gap which, because of the deposition of splash over time, increases in size. Explosions and fires on industrial sites as a result of welding and/or heat treating operations are, unfortunately, a relatively common occurrence, and this spark gap is probably the source of more such accidents than any other single component welding equipment.

In addition to these safety problems, because the contacters are expensive (even a small contacter may cost the contractor $75-90, most are in the $300-400 range, and large contacters may cost up to $1500), they are usually sized to the job; in other words, a much larger contacter is used in a contacter box on a job requiring 80 volts at 500 amperes than a job requiring 40 volts at 200 amperes. It is common to use the same contacter box (within certain power ranges) and switch out the contacters. Predictably, the used contacters end up being thrown into a box, and after several jobs, the welding contractor accumulates a wide assortment of used, but still usable, contacters. A problem arises when used contacters are subsequently re-used on jobs for which they may not be properly sized, thereby creating a safety hazard. The method and apparatus of the present invention eliminate the contacter box and the attendant safety problems from the circuit, and as noted above, the primary goal of the present invention is to increase the safety of using an applications power supply.

A controller, indicated generally at reference numeral **10**, constructed in accordance with the present invention is shown in FIG. 1, which represents a system suitable for heat treating workpiece **12**. The system includes a temperature sensing means such as a thermocouple or other temperature sensor **14** as are well-known in the art connected to controller **10** by a pair of leads **16** for sensing the temperature of workpiece **12** and outputting a signal proportional thereto. Controller **10** is provided with a first connector, indicated generally at **18**, for receiving input power from an external power source (not shown), normally either 120 or 240 volt, single phase, and second connector **20** for transmitting an output signal therefrom to an applications power supply **22**. Applications power supply **22** is, for instance, a conventional rectifier or voltage inverter having positive and negative terminals **24** and **26**, respectively, to which cables **28** and **30** are connected for powering a heating element such as a ceramic heating pad **32**. Applications power supply **22** likewise receives input power from an external source (not shown) or primary line, such as a generator, normally supplying 120/240 volt, single phase current or 240-575 volt, three phrase current.

Referring now to FIG. 2, the controller **10** is shown in more detail. In a presently preferred embodiment, controller **10** includes two major components, the first of which comprises means operating on the power received from an input power cable, or first connector **18**, which receives the signal from temperature sensing means **14** and outputs a signal responsive to the difference between a desired temperature and the temperature sensed by sensing means **14** in the form of, for instance, a temperature sensor/controller, or comparator **34**. Temperature sensor/controller **34** outputs a signal responsive to the difference between a desired temperature selected by the operator with control knob **36** thereof and the temperature sensed by thermocouple **14** through second connector **20** to turn applications power supply **22** on and off. In a presently preferred embodiment, comparator **34** comprises a Honeywell "DIAL-A-PACK" controller, but those skilled in the art who have the benefit of this disclosure will recognize that other similar controllers will function equally well for this intended purpose. Controller **10** is optionally provided with a timer for manually determining a time at which heating operations are to begin.

The second major component of controller 10 comprises means for limiting the current of the signal output from temperature sensor/controller 34 that, in turn, outputs a current limited signal proportional to a desired power level of the applications power supply 22 to control the rate of heating of the metallic workpiece by heating element 32. This current limiting means, in a presently preferred embodiment, takes the form of a potentiometer 38, having output power knob 40 (see FIG. 1) calibrated in percentage power output of the applications power supply 22, for selection of the desired power level of the applications power supply 22 by the operator. The current limited output signal of potentiometer 38 is then transmitted to applications power supply 22 through second connector 20. Means is optionally provided, in the form of a second potentiometer 48 and interval timer-controlled switch 50 (both shown in shadow lines in FIG. 2 because they are optional) for switching back and forth between circuits including potentiometer 38 and potentiometer 48 at selected time intervals, or frequency, to pulse the power output of applications power supply 22 from a first power level to a second power level. As is apparent to those skilled in the art from the forgoing description, appropriate control or selector knobs (not shown) are provided for selecting the second power level using potentiometer 48 and the frequency with which switch 50 switches back and forth between potentiometer 38 and potentiometer 48. As shown in FIG. 2, controller 10 is also provided with an on/off switch 42, "power on" indicator lamp 44, and re-settable ground fault fuse 46, all as known in the art.

Connector 20, in a presently preferred embodiment, is an amphenol-type and plugs directly into certain commercially available applications power supplies which are provided with input jacks for remote controllers used during welding operations. For instance, the Model MP 1500, 2800, 3500, and 5000 power inverters available from Kemppi Inc. (Mentor, Ohio) all include an input jack for such an amphenol-type connector into which, for instance, a Kemppi C100C remote control is plugged for stepless adjustment of current ranges and/or pulse ratio during welding operations. Such remotes include controls that duplicate the percentage power output selector knob 50 of applications power supply 22, and output power knob 40 of potentiometer 38 of controller 10 of the present invention effectively functions in place of selector knob 50. Although not limited to use solely with an inverter or solid state power supply, there are advantages to using controller 10 of the present invention with such power supplies, specifically, electronic power control on the primary side and electronic regulation with low power control. By using other connectors and/or adapters (not shown), controller 10 of the present invention is used for heat treatment with any applications power supply that includes a remote control input jack.

As noted above, controller 10 is powered by an external power source. That external power source can be powered by a battery, 120 or 240 volt 50/60 Hz single phase source, or other readily available power source as is known to those skilled in the art who have the benefit of this disclosure, when combined with the proper converter and/or other circuitry for operating on that power source. As is clear from the preceding description, the power levels on which controller 10 operates, and the output signal thereof, are but a fraction of the power levels which some applications power supplies are capable of producing. Such low power levels, along with the elimination of a control box including the contacters, make the use of the controller 10 for operating an applications power supply much safer than the manner in which conventional power supplies are used for heat treatment. Further, the added convenience of the automatic on and off cycling of applications power supply 22 under the influence of controller 10 once the sensed temperature and the desired temperature are equal, greatly facilitates proper heat treatment.

In an alternative embodiment (not shown), the temperature sensor/controller, or comparator, 34 is replaced by a programmable timer. Such a programmable means allows the operator to begin operations at a predetermined time to heat metal to a desired temperature at a desired rate, both the desired temperature and the rate of heating (e.g., percentage power) being predetermined and programmed into such a device, as well as the time of commencement of operations. Regardless of whether a programmable means is provided, the present invention optionally contemplates the use of a chart recorder for monitoring the temperature of the metal, lapsed time of operation, and/or the duty cycle of applications power supply 22 as a function of time as known in the art.

Referring again to the figures, the method of the present invention will now be described. If, for instance, it is desired to preheat a weld joint between chrome/-molyodenom steel, four inch O.D., W.T. 0.5 inches, the interpass temperature during welding would be between about 375° and 700° F. Controller 10 is operated, for instance, from a 120 V AC, 50/60 Hz single phase outlet, and a power inverter such as the Kemppi model MP 1500 inverter type power supply is connected to a 220 V AC, 50/60 Hz single phase primary source. Two heating pads are attached to workpiece 12, one on each side of the joint about four to six inches from the centerline of the joint as is shown for heating element 32 in FIG. 1. Ceramic fiber insulation is then affixed around each heating pad and thermocouple 14 is inserted between one of the heating pads and the weld joint.

The pair of leads 16 of thermocouple 14 is connected to controller 10 and positive and negative terminals 24 and 26 of the inverter are connected to the heating pads using two dual splitters (not shown). Second connector 20 is connected to the remote input jack on applications power supply 22, and the appropriate switch (not shown) on that applications power supply 22 is positioned for remote operation. Using selector knob 36 of controller 10, the desired temperature is set at between about 357° and 700° F., and selector knob 40 of the controller 10 is used to select a desired percentage power output, for instance, about 40%. Using this particular power supply, the 40% desired power level limits output power to 60 amperes on a 100% duty cycle, each heating pad drawing a nominal 30 amperes. Both controller 10 and applications power supply 22 are then switched on.

The temperature of workpiece 12 is then sensed and compared to the desired temperature, and comparator 34 output a signal if the sensed temperature is less than the desired temperature (e.g., a "difference" signal). The current of that difference signal output by comparator 34 is then limited to a level proportional to the 40% desired power level of applications power supply 22 and then transmitted to applications power supply 22 to switch the power supply on. Depending upon the circuitry of comparator 34 (see above), the sensed temper-

ature of workpiece 12 and the desired temperature are either compared continuously or at regular intervals until they are approximately equal, at which time applications power supply 22 is turned off when comparator 34 ceases outputting the difference signal. As noted above, by activating the timer-controlled switch 50, applications power supply 22 is optionally switched between first and second power levels at a desired frequency.

Although heating element 14 is shown as a ceramic heating pad, it is not intended that the apparatus of the present invention be so restricted. Instead, any electrically operated heating element such as a finger element, braided heater, or electrically operated infrared heater, may be used to advantage as a heating element in connection with the present invention. Further, it will be apparent that the applications power supply 22 is also capable of being used to power a heating element 14 which is used to heat the air inside a closed metal workpiece, such as a boiler or reaction vessel, to heat treat in a manner similar to the heating of an oven under the control of controller 10. As noted above, the heating need not be restricted to heat treating operations, it being an advantageous use of controller 10 of the present invention to provide heat for thawing, increasing the fluidity, or preventing freezing, of the contents of a metal container, or conduit. Other modifications to the specific embodiment described herein will be apparent to those skilled in the art, and all are intended to fall within the spirit and scope of the following claims.

What is claimed is:

1. An apparatus for controlling the heating of metal to a desired temperature comprising:
   - means for sensing the temperature of the metal to be heated and outputting a signal proportional thereto;
   - a first connector for receiving input power from an external power source;
   - means operating on the power received from said first connector and receiving the signal from said temperature sensing means for outputting a signal responsive to the difference between a desired temperature and the temperature sensed by said sensing means to turn an applications power supply that powers a heating element on and off;
   - means for limiting the current of the signal from said signal outputting means and outputting a current limited signal proportional to a desired power level of the applications power supply to control the rate of heating of the metal by the heating element; and
   - a second connector for transmitting the signal of said current limiting means to the applications power supply.

2. The apparatus of claim 1 wherein said signal outputting means outputs a low power signal from power received from said first connector and the applications power supply produces high power levels for powering the heating element.

3. The apparatus of claim 1 wherein said signal outputting means is programmable to begin operations at a predetermined time to heat the metal to a desired temperature at a desired rate.

4. The apparatus of claim 1 additionally comprising means for recording the duty cycle of the applications power supply or the output signal of said temperature sensing means.

5. The apparatus of claim 1 wherein the applications power supply is an inverter power supply.

6. The apparatus of claim 1 wherein said temperature sensing means is a thermocouple.

7. The apparatus of claim 1 wherein the heating element is a heating pad.

8. The apparatus of claim 1 additionally comprising means for switching between first and second current limited output signals at a selected frequency for pulsing the applications power supply.

9. An apparatus for use in stress relieving, or in a welding operation requiring pre-heating or post-heating of a metallic workpiece, wherein the metallic workpiece is heated to a desired temperature and held at or near the desired temperature for a desired period of time comprising:
   - a temperature sensor for outputting a signal proportional to the temperature of a metallic workpiece;
   - a first connector for receiving input power from a source of low power;
   - a comparator operating on the low power received from said first connector and receiving the signal from said temperature sensor for outputting a signal responsive to a difference between a desired temperature and the temperature of the workpiece to turn on a high applications power supply that powers a heating element, thereby increasing the temperature of the workpiece;
   - means for limiting the current of the signal from said comparator and for outputting a signal proportional to a desired power level of the applications power supply to control the rate of heating of the workpiece by the heating element; and
   - a second connector for transmitting the signal of said current limiting means to the applications power supply.

10. The apparatus of claim 9 additionally comprising programmable means for beginning operations at a predetermined time to heat the workpiece at a desired rate to a desired temperature for a desired period of time.

11. The apparatus of claim 9 wherein said comparator produces low voltage output signal and the applications power supply is capable of producing power having a current as high as several thousand amperes.

12. A method for controlling the heating of a metal to a desired temperature comprising the steps of:
   - selecting a temperature to which it is desired to heat a metallic workpiece;
   - sensing the temperature of the workpiece;
   - comparing the sensed temperature of the workpiece to the desired temperature;
   - outputting a signal if the sensed temperature is less than the desired temperature;
   - limiting the current of the output signal to a level proportional to a desired power level of an applications power supply; and
   - transmitting the current limited output signal to the applications power supply to switch the applications power supply on to heat the workpiece.

13. The method of claim 12 wherein the applications power supply powers a heating element.

14. The method of claim 12 additionally comprising beginning the steps of the method at a predetermined time with a preselected desired temperature and a preselected desired power level under control of a programmable means.

15. The method of claim 12 additionally comprising turning the applications power supply off when the sensed temperature of the workpiece is approximately equal to the desired temperature.

16. The method of claim 12 wherein the applications power supply produces high current power and is turned on by the current limited, low power signals.

17. The method of claim 16 wherein the high current power is in the range of thousands of amperes.

18. The method of claim 12 wherein the temperature of the workpiece and the desired temperature are compared either continuously or at regular intervals.

19. The method of claim 12 wherein different current limited output signals are transmitted to the applications power supply to pulse the output power produced by the applications power supply.

20. The method of claim 19 additionally comprising switching back and forth between the different current limited output signals at a selected frequency.

* * * * *

US-PAT-NO: 5397876

DOCUMENT-IDENTIFIER: US 5397876 A

TITLE: High frequency bolt heater having induction heating coil

---------- KWIC ---------

Detailed Description Text - DETX (9):

In testing the invention, after the above procedures were carried out, the inventors measured **temperatures** at three places along the outer surface of the bolt 12 (at the longitudinally middle portion thereof, at the surface of the nut 15 and at the casing flange 11) by attaching thermoelectric thermometers and by **recording** via a **temperature recorder** from the beginning of heating to the completion of cooling.

US005397876A

# United States Patent [19]

**Shimamoto et al.**

[11] **Patent Number:** 5,397,876

[45] **Date f Patent:** Mar. 14, 1995

[54] **HIGH FREQUENCY BOLT HEATER HAVING INDUCTION HEATING COIL**

[75] Inventors: **Takijiro Shimamoto; Yoji Morita; Ichiro Shimasaki; Ichiro Matsuura,** all of Nagasaki; **Tsukasa Maenosono,** Kawasaki, all of Japan

[73] Assignees: **Mitsubishi Jukogyo Kabushiki Kaishi; Dai-ichi High Frequency Co., Ltd.,** both of Tokyo, Japan

[21] Appl. No.: **177,956**

[22] Filed: **Jan. 6, 1994**

[30] **Foreign Application Priority Data**

Jan. 7, 1993 [JP] Japan .................... 5-017109

[51] **Int. Cl.⁶** .................... **H05B 6/14**

[52] **U.S. Cl.** .................... **219/644**; 219/673; 219/635; 219/670; 219/676

[58] **Field of Search** .................... 219/644, 613, 673, 670, 219/676, 643, 635, 637

[56] **References Cited**

U.S. PATENT DOCUMENTS

| | | | |
|---|---|---|---|
| 2,176,601 | 10/1939 | Bates . | |
| 2,397,629 | 4/1946 | Stevens | 219/644 |
| 2,810,053 | 10/1957 | Messner | 219/644 |
| 3,236,993 | 2/1966 | Jones | 219/670 |
| 3,393,286 | 7/1968 | Zandstra | 219/613 |
| 4,100,387 | 7/1978 | Reinke et al. | 219/673 |
| 4,574,172 | 3/1986 | Burack et al. | 219/644 |
| 4,590,347 | 5/1986 | Thatcher et al. | 219/644 |

FOREIGN PATENT DOCUMENTS

| | | |
|---|---|---|
| 965761 | 7/1949 | Germany . |
| 1050935 | 2/1959 | Germany . |
| 535202 | 4/1941 | United Kingdom . |
| 565130 | 8/1977 | U.S.S.R. . |

*Primary Examiner*—Philip H. Leung
*Attorney, Agent, or Firm*—Wenderoth, Lind & Ponack

[57] **ABSTRACT**

A high frequency bolt heater is provided which can heat up the inside of a narrow hole much faster than a conventional bolt heater employing a resistance wire. The high frequency bolt heater includes an induction heating coil made of a copper tube bent in a hairpin fashion and whose shape is made approximately circular in section by pinching a magnet between opposed portions thereof. The heater can be inserted into a hole bored in the axial direction of a metallic bolt. A length of the coil is made approximately equal with that of the bored hole, and the magnet is omitted from a region of the heater which corresponds to a screw portion of the bolt for mounting a nut. An adjustable stopper made of a heat resistant electrical insulator is provided for setting a necessary length of the induction heating coil to be inserted into the hole, and a heat resistant insulator is provided on the surface of the induction heating coil.

**14 Claims, 5 Drawing Sheets**

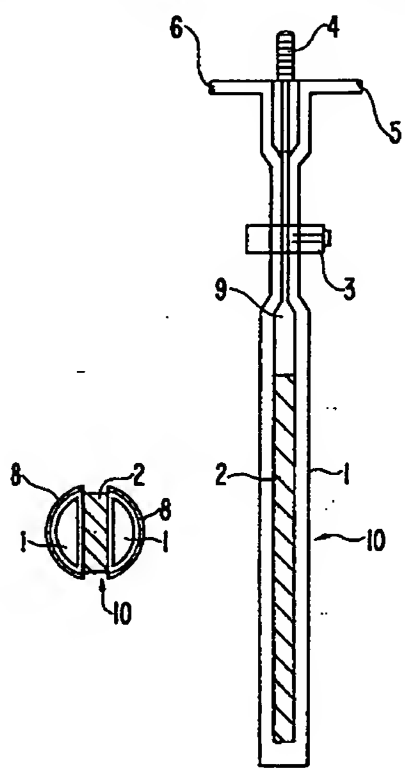


FIG. 1

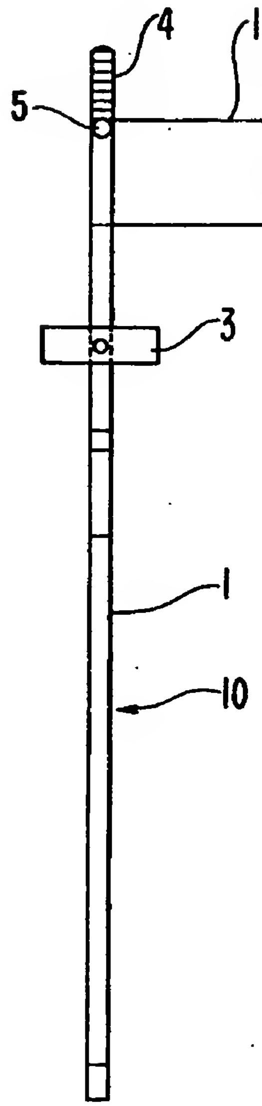


FIG. 2(a)

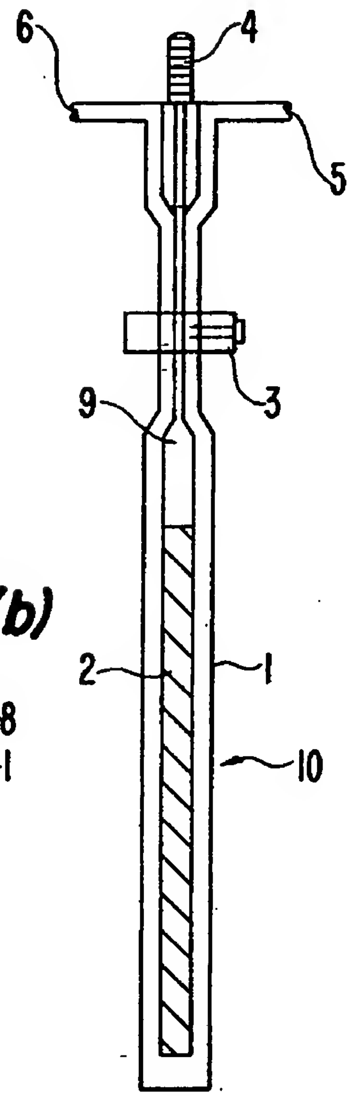



FIG. 2(b)

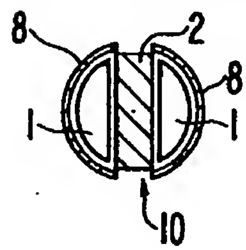


FIG. 3

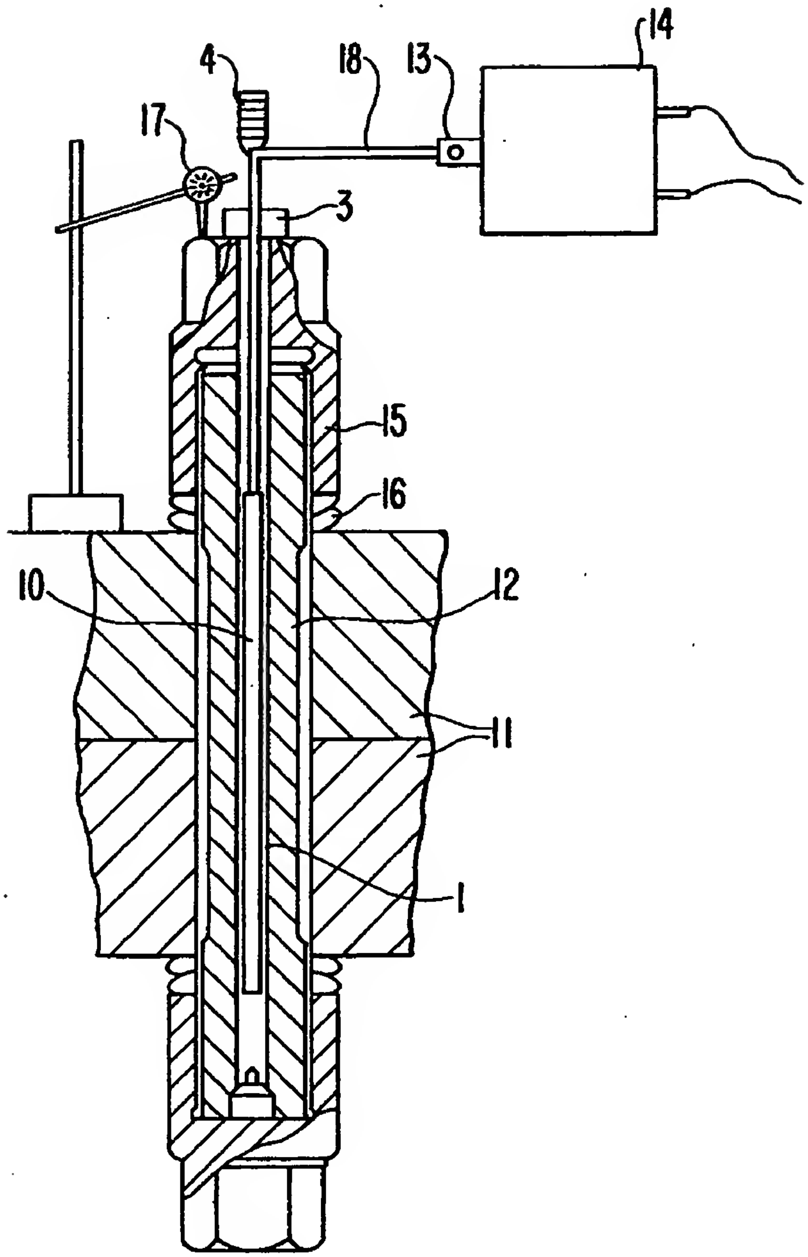


FIG. 4
(PRIOR ART)

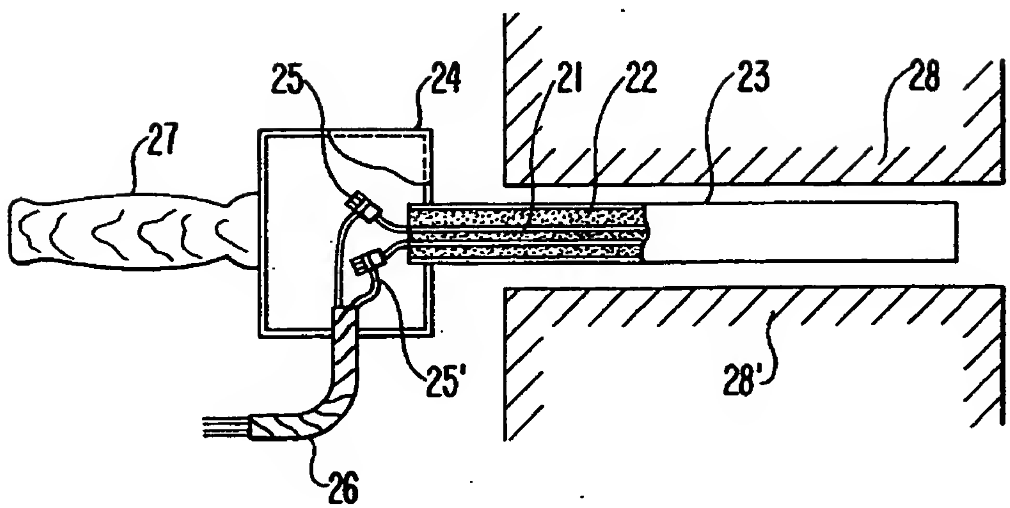


FIG. 5
(PRIOR ART)

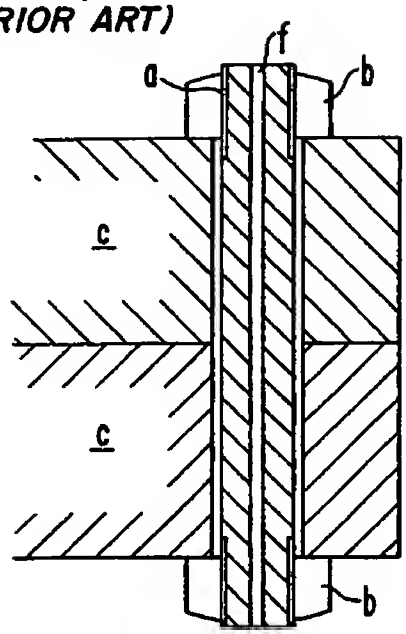
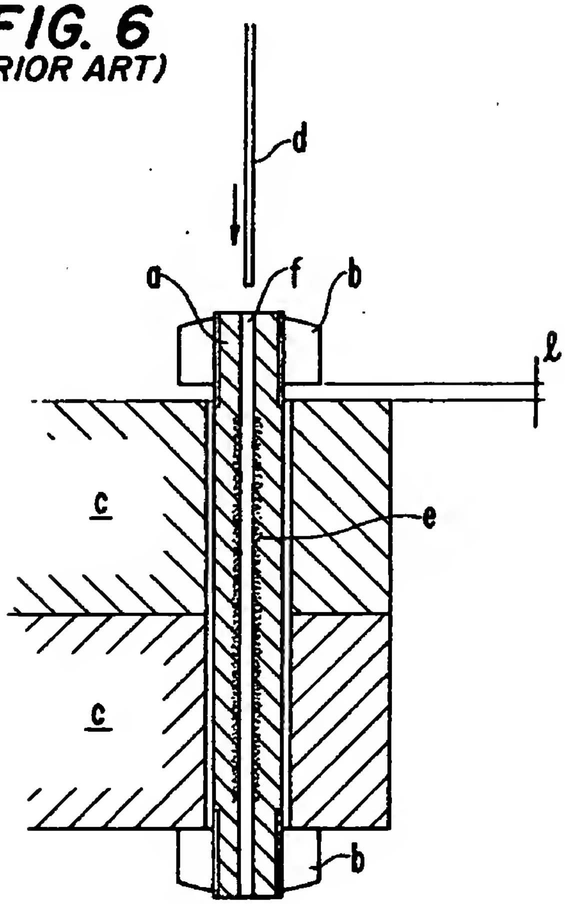



FIG. 6
(PRIOR ART)



# HIGH FREQUENCY BOLT HEATER HAVING INDUCTION HEATING COIL

## BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a bolt heater used for fastening and loosening bolts of a steam turbine casing, etc., applicable for a heating system for heating large size bolts of other various machines and for heating a narrow and long hole from the inside thereof, and usable where heating cannot be done from the outside such as a heat treatment within a narrow hole, heating of a boiler tube, heating of an inner tube of a double tube and improvement of stress in a welded section of a narrow hole.

2. Description of the Related Art

A bolt heater is used for fastening or loosening a large size bolt which is used for a steam turbine casing for example and which cannot be fastened by a wrench or spanner.

A case when a bolt heater is used for loosening a bolt will be explained referring to FIGS. 5 and 6. FIG. 5 shows a pair of flanges (C) strongly fastened by a bolt (a) and nuts (b). When a bolt heater (d) is inserted to a center hole (f) bored at the center of the bolt (a) in the longitudinal direction thereof and the bolt (a) is heated by the bolt heater (d), the bolt (a) thermally expands in the axial direction by a length (1) as shown in FIG. 6. Thereby, the nut (b) can be rotated easily and be loosened.

In this case, it is only necessary to heat a parallel portion (e) of the bolt (a), and it is preferable to avoid heating the screw portions of the bolt and nut to the extent possible.

In fastening the bolt, the bolt (a) is similarly heated up to thermally expand in the axial direction thereof. When the bolt (a) is expanded, the nut (b) is rotated in the direction of fastening the bolt (a). Then the bolt (a) is cooled down to obtain a predetermined fastening force.

Conventionally, a bolt heater constituted by a resistance wire heating element is inserted into center holes of bolts for lateral joint faces or the like of a steam turbine casing for use on land or aboard ship, in order to fasten or loosen the bolts.

Referring now to FIG. 4, one example of a prior art heater constituted by a resistance wire will be explained. In the figure, resistance wire heating elements 21 are embedded in a heat resistant insulator 22. A jacket 23 is made of a heat resistant metal such as SUS. A handle 27 is attached to a terminal box 24. Terminals 25 and 25' connect the resistance wire heating elements 21 with a cable 26. The reference numerals 28 and 28' indicate cross sections of an object to be heated such as a bolt.

In FIG. 4, when power is supplied by connecting the cable 26 to a power supply which is not shown, the resistance wire heating elements 21 generate heat and the jacket 23 is heated up through the intermediary of the heat resistant insulator 22.

However, because the resistance wire heating elements 21 are embedded in the heat resistance insulator 22 within a narrow stainless tube in the conventional bolt heater shown in FIG. 4, a quantity of heat input is limited, and because the heating is carried out indirectly, it is inefficient. Due to that, it takes a long time to fasten or loosen the bolts and has been a bottleneck in the assembly process for a turbine. Further, because it takes a long time for heating, and the resistance wire heating element 21 is exposed in a high temperature state for a long time, it is deteriorated appreciably.

In addition, because the nut portion and flanges of the casing are also heated up and thermally expanded due to the long heating, an error is brought about in a necessary elongation length of the bolt, thereby complicating its management.

Because the temperature does not rise quickly, not only are a number of heaters required (also for bolts whose length differ), but also there is a danger that an operator may touch the hot nuts and casing flanges.

Accordingly, it is an object of the present invention to eliminate the aforementioned problems by providing a high frequency bolt heater which can heat up the inside of a narrow hole much faster than the prior art bolt heater using the resistance wire heating element.

## SUMMARY OF THE INVENTION

According to the present invention, a high frequency bolt heater comprising an induction heating coil is inserted into a hole bored in the axial direction of a metallic bolt. The coil is made approximately circular in section by pinching a magnet between reciprocating paths (i.e. opposing portions) of a copper tube turned bent in a hairpin fashion, and a length of the coil is approximately equal with that of the bored hole. The magnet is omitted at a region of the coil which, when the heater is disposed in the axial bore, corresponds in position to a screw portion of the bolt for mounting a nut.

The high frequency bolt heater of the present invention is provided with an adjustable stopper made from a heat resistant electrical insulator for setting a length of the coil to be inserted into the bolt hole.

Further, the high frequency bolt heater of the present invention uses a flexible member for connecting the induction heating coil and a high frequency transformer.

As described above, the magnet provided between the reciprocating paths (or opposing portions) of the coil bent in a hairpin fashion is omitted at the region of the coil which corresponds to the screw portion of the nut and bolt. Because a distance between the reciprocating paths of the coil where the magnet is omitted is narrow, magnetic flux which penetrates through an object to be heated is cancelled out and it is almost impossible to heat in this portion. Therefore, a range in which the magnet is provided is an effective heating zone and the inside of the narrow hole can be heated up rapidly and efficiently. The length of the zone can be changed by adjusting the length of the magnet pinched between the coils, so that this high frequency bolt heater can be used with bolts of different lengths.

The above and other related objects and features of the present invention will be apparent from a reading of the following description of the disclosure found in the accompanying drawings and the novelty thereof pointed out in the appended claims.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side view of an embodiment of a high frequency bolt heater of the present invention;

FIGS. 2*a* and 2*b* are a front view of the heater and a second view thereof respectively;

FIG. 3 is a side section view showing the present invention applied to a steam turbine;

FIG. 4 is a section view of a prior art resistance wire heater;

FIG. 5 is a side section view of a bolt into which the prior art bolt heater is inserted; and

FIG. 6 is a side section view of the bolt shown in FIG. 5 showing a state when it has thermally expanded.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings wherein like reference numerals refer to like parts throughout several views, a preferred embodiment of the present invention will be explained. FIGS. 1 through 3 show the embodiment of the present invention, wherein FIG. 1 is a side view of a high frequency bolt heater of the present invention, FIG. 2*a* is a front view thereof, FIG. 2*b* is a section view thereof and FIG. 3 shows the present invention as applied to a bolt for fastening lateral joint faces of a steam turbine casing.

In the high frequency bolt heater 10 shown in FIGS. 1 and 2, a coil 1 made from a copper tube turned around in a hairpin fashion is formed into an approximately circular cross-sectional shape by removably pinching a magnet 2 between opposed portion of the coil 1. A length of the coil 1 is made equal to that of a hole bored in a metallic bolt 12 into which the bolt heater 10 is inserted. A magnet-free section 9 in which the magnet 2 is omitted is, when the heater 10 is inserted into the bolt 12, positioned at a region which corresponds to a threaded portions of the bolt 12 for use in mounting a nut 15. The magnet-free section constitutes a non-heating section.

A stopper 3 made of a heat resistant electrical insulator is provided on the coil 1 to set a length of the high frequency bolt heater 10 to be inserted into the metallic bolt 12, and the fixed position of the stopper 3 on the coil 1 can be changed by loosening a screw thereof. The surface of the high frequency bolt heater 10 is covered by a heat resistant insulator 8. The high frequency bolt heater 10 is also provided with a handle 4, an inlet port 5 for supplying water to the coil 1, an exhaust port 6 for draining water from the coil 1 and a power feeding section 13 for feeding power to the coil 1.

The high frequency bolt heater 10 will now be explained in more detail. The coil 1 is made of the copper tube which is a good electrical conductor and which is formed into a semicircular tube (i.e. a tube having a semicircular cross section) defining a water channel therein. The surface of the coil 1 covered by the heat resistant insulator 8 is insulated, for example, by thermal spray coating an alumina insulator thereon or by winding a glass tape thereabout. The outer diameter of the coil 1 is made smaller than the diameter of the hole of the bolt by 1 to 2 mm considering heating efficiency.

In operation, the coil 1 having a construction as exemplified in FIG. 2 is inserted into the center hole of the bolt 12 as shown in FIG. 3. The length of the coil 1 to be inserted is set beforehand by means of the adjustable stopper 3 provided on the coil 1. A region to be heated may be selected by loosening the screw provided on the stopper 3 and fastening it after moving the coil 1 in the axial direction.

A current flows from a power source, which is not shown, to the power feeding section 13 and to the coil 1 through the intermediary of a high frequency transformer 14. When heat is generated by the heater 10 from the inner surface of the hole of the bolt 12, the bolt 12 elongates in a few minutes due to its thermal expansion.

As shown in FIG. 3, the high frequency bolt heater 10 is inserted into the narrow hole of the metallic bolt 12, which secures lateral joint flanges 11 of a casing, until the bolt heater 10 reaches the position determined by the stopper 3, and the power feeding section 13 is connected to the high frequency transformer 14. A spherical washer 16 is disposed between the nut 15 screwed on the bolt 12 and the lateral joint flange 11. The reference numeral 17 denotes a dial gauge. A flexible member such as a flexible cable is used as a member 18 for connecting the coil 1 and the high frequency transformer 14.

In testing the invention, after the above procedures were carried out, the inventors measured temperatures at three places along the outer surface of the bolt 12 (at the longitudinally middle portion thereof, at the surface of the nut 15 and at the casing flange 11) by attaching thermoelectric thermometers and by recording via a temperature recorder from the beginning of heating to the completion of cooling.

The elongation of the bolt 12 was measured by using the dial gauge 17 while contacting it with the head of the nut 15 and securing it at a position which would not be influenced by an elongation of the casing.

Tables 1, 2 and 3 show the results of the measurements described above.

TABLE 1

| Tested Bolts & Nuts | | | |
|---|---|---|---|
| Bolt No. | Size (dia. × length) | Type | Necessary Elongation (mm) |
| 1 | 101 × 1275 | Double-end nut & bolt | 1.7 |
| 2 | 108 × 1315 | Reamer double-end nut & bolt | 1.7 |
| 3 | 101 × 925 | Stud bolt with bottom | 1.1 |

TABLE 2

| Measured Result | | | | | |
|---|---|---|---|---|---|
| Bolt No. | Heating time (sec) | Temp. of bolt (°C.) | Temp. of nut (°C.) | Temp. of flange (°C.) | Length elongated (mm) |
| 1 | 540 | 204 | normal temp. | 39 | 2.73 |
| 2 | 450 | 258 | normal temp. | 39 | 1.74 |
| 3 | 360 | 180 | normal temp. | 18 | 1.76 |

TABLE 3

| Electrical Condition | |
|---|---|
| Bolt No. | Output (kw) |
| 1 | 20 |
| 2 | 20 |
| 3 | 20 |

As described above, according to the present invention, the magnet provided along the axial direction between the reciprocating paths (i.e. opposed portions) of the coil bent in the hairpin fashion is omitted at the portion which corresponds to the screw portion of the nut and bolt when the heater is inserted in the bolt. Because a pitch of the reciprocating paths (i.e. distance between the opposed portions) of the coil where the magnet is omitted is narrow, magnetic flux which penetrates through an object to be heated is cancelled out and it is almost impossible to heat in this portion. Therefore, the range in which the magnet is provided is an effective heating zone. The length of the zone can be

changed by adjusting the length of the magnet pinched between the coils, so that this high frequency bolt heater can be applied to bolts of different lengths. Accordingly, the present invention is effective to heat up the inside of a narrow hole rapidly and efficiently by causing a current to flow through the high frequency bolt heater. Thereby, with the present invention bolts can be heated about 10 times faster than with the prior art bolt heater employing the resistance wire, so that the time and labor required for assembling a steam turbine or the like may be considerably reduced.

Further, because the screw portion for mounting the nut and the flange portion of the casing are not directly heated up, the elongation of the bolt may be accurately measured. Also, because the flexible member is used for the connection between the induction heating coil and the high frequency transformer in the present invention, the connection and operation of both can be readily implemented. The heating can be suppressed and the problem of deterioration of the heater due to the repetitive heating may be eliminated by providing the water channel in the coil.

While the described embodiment represents the preferred form of the present invention, it is to be understood that modifications will occur to those skilled in that art without departing from the spirit of the invention. The scope of the invention is therefore to be determined solely by the appended claims.

What is claimed is:

1. A high-frequency bolt heater for use in heating a bolt having an axial hole, said heater comprising:

an elongated induction coil comprising a conductive tube formed in a substantially U-shape having a pair of substantially parallel leg portions, each of said leg portions having a substantially semicircular cross-sectional shape;

an elongated magnet sandwiched between said leg portions of said induction coil along a first portion thereof, said leg portions of said induction coil being devoid of a magnet therebetween along a second portion of said induction coil, said first portion constituting a heating portion and said second portion constituting a non-heating portion;

wherein, along said heating portion, said leg portions together with said magnet sandwiched therebetween have a substantially circular cross-sectional shape.

2. A heater as recited in claim 1, wherein

said conductive tube comprises a copper tube.

3. A heater as recited in claim 1, further comprising

an adjustable stopper, formed of a heat resistant electrically insulating material and adjustably mounted to said conductive tube, for regulating a length by which said induction coil is inserted into the axial hole of the bolt.

4. A heater as recited in claim 1, further comprising

an adjustable stopper, formed of a heat resistant electrically insulating material and adjustably mounted to said conductive tube, for regulating a length by which said induction coil is inserted into the axial hole of the bolt, and for causing said non-heating portion to be positioned at a predetermined location in the axial hole which is to not be heated.

5. A heater as recited in claim 1 wherein

said leg portions of said conductive tube have inwardly facing exterior surfaces facing toward one another, and outwardly facing exterior surfaces facing away from one another; and

a heat resistant insulator is provided over said outwardly facing exterior surfaces.

6. A heater as recited in claim 1, wherein

said leg portions of said conductive tube have inwardly facing exterior surfaces facing toward one another, and outwardly facing exterior surfaces facing away from one another; and

said outwardly facing exterior surfaces of said leg portions constitute, in cross section, a majority of an outer periphery of said substantially circular cross-sectional shape.

7. A heater as recited in claim 1, further comprising

a high frequency transformer operably connected to said induction heating coil; and

a flexible member connecting said induction heating coil to said high frequency transformer.

8. A high-frequency bolt heater for use in heating a bolt having a predetermined length, an axial hole, and a threaded portion for engaging a nut, said heater comprising:

an elongated induction coil for insertion into the axial hole of the bolt and comprising a conductive tube formed in a substantially U-shape having a pair of substantially parallel leg portions, each of said leg portions having a substantially semicircular cross-sectional shape and being of a length approximately equal to a length of the axial hole;

an elongated magnet sandwiched between said leg portions of said induction coil along a first portion thereof, said leg portions of said induction coil being devoid of a magnet therebetween along a second portion of said induction coil, said first portion constituting a heating portion and said second portion constituting a non-heating portion which, when said induction coil is inserted in the axial hole, corresponds in position along said induction coil to a position of the threaded portion of the bolt;

wherein, along said heating portion, said leg portions together with said magnet sandwiched therebetween have a substantially circular cross-sectional shape.

9. A heater as recited in claim 8, wherein said conductive tube comprises a copper tube.

10. A heater as recited in claim 8, further comprising

an adjustable stopper, formed of a heat resistant electrically insulating material and adjustably mounted to said conductive tube, for regulating a length by which said induction coil is inserted into the axial hole of the bolt.

11. A heater as recited in claim 8, further comprising

an adjustable stopper, formed of a heat resistant electrically insulating material and adjustably mounted to said conductive tube, for regulating a length by which said induction coil is inserted into the axial hole of the bolt, and for causing said non-heating portion to be positioned at the threaded portion of the bolt.

12. A heater as recited in claim 8, wherein

said leg portions of said conductive tube have inwardly facing exterior surfaces facing toward one another, and outwardly facing exterior surfaces facing away from one another; and

a heat resistant insulator is provided over said outwardly facing exterior surfaces.

13. A heater as recited in claim 8, wherein

said leg portions of said conductive tube have inwardly facing exterior surfaces facing toward one

another, and outwardly facing exterior surfaces facing away from one another; and

said outwardly facing exterior surfaces of said leg portions constitute, in cross section, a majority of an outer periphery of said substantially circular cross-sectional shape.

14. A heater as recited in claim 8, further comprising

a high frequency transformer operably connected to said induction heating coil; and

a flexible member connecting said induction heating coil to said high frequency transformer.

* * * * *

US-PAT-NO: 3637985

DOCUMENT-IDENTIFIER: US 3637985 A

TITLE: PORTABLE REMOTE LOCATION MEASURING SYSTEM

---------- KWIC ---------

Brief Summary Text - BSTX (8):
While the thermocouple overcomes many of the disadvantages of other prior art devices, it has not proved to be completely successful due at least partially to bulkiness and a requirement for associated usage of unwieldly equipment, particularly where long oven usage was contemplated. More specifically, if the thermocouple is to travel with the ware riding on a belt through the annealing oven, wire conductors have heretofore been necessary in order to conduct the electrical signal from the thermocouple to a temperature meter or **recorder** outside the oven for prompt indication. Besides being cumbersome, the added effective resistance of the wires subjected to varying oven temperatures tended to introduce errors which often made the obtained readings so inaccurate as to be unreliable.

Detailed Description Text - DETX (3):
A thermocouple 24 is attached to the surface of a jar 16 by any conventional means such as by a tape or by a suitable

temperature-resistant bonding adhesive. The temperature of the particular jar 16 is sensed by the thermocouple 24 and the corresponding signal conducted through wires 25 to the transmitting unit 14. The temperature signal is thereupon processed as more fully hereinafter described with reference to FIG. 6 and a corresponding radiant energy signal is transmitted out of the oven 10 to a receiver 26, preferably located outside the oven, the output signal from which receiver may be immediately indicated by a temperature meter (not shown) and/or permanently **recorded** on a time-temperature **recorder** 28.

Current US Cross Reference Classification - CCXR (4):

**219/667**

# United States Patent

Stacey

[15] 3,637,985

[45] Jan. 25, 1972


## [54] PORTABLE REMOTE LOCATION MEASURING SYSTEM


[72] Inventor: David S. Stacey, Carbondale, Colo.

[73] Assignee: Ball Corporation, Muncie, Ind.



[22] Filed: Jan. 21, 1969

[21] Appl. No.: 792,395

[52] U.S. Cl. ....219/490

[51] Int. Cl. ....H05b 1/02

[58] Field of Search ....219/210, 490, 501, 401; 73/359, 341, 362; 340/208, 224; 307/117; 325/113, 67; 220/17; 165/75


[56] **References Cited**

UNITED STATES PATENTS

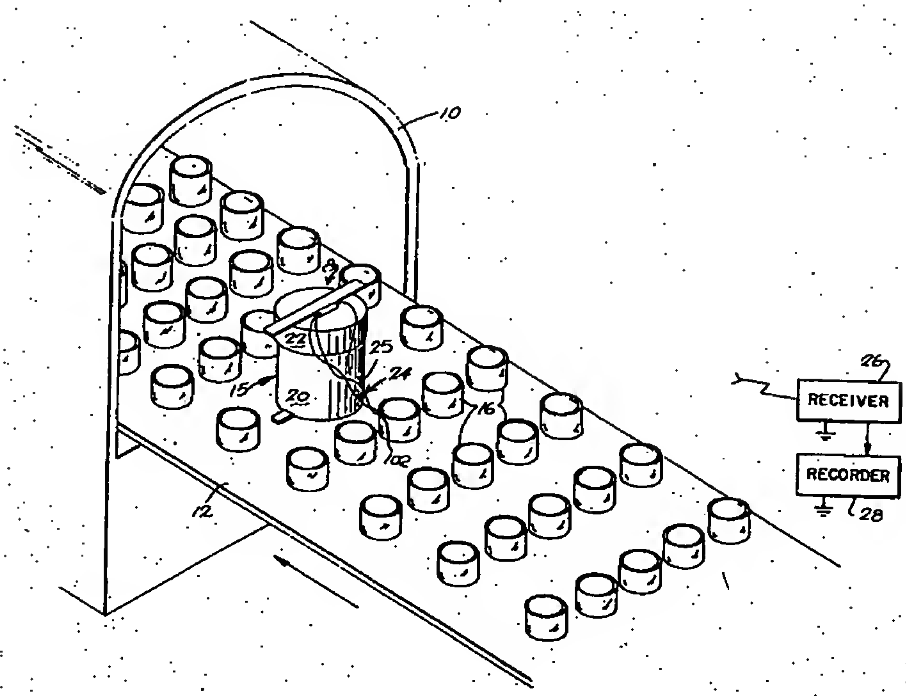

| | | | |
|---|---|---|---|
| 1,323,525 | 12/1919 | Dutton | 219/401 X |
| 1,958,590 | 5/1934 | Peirce | 219/401 |
| 2,635,468 | 4/1953 | Field et al. | 73/341 X |
| 2,818,732 | 1/1958 | Bennett | 73/362 |
| 2,992,120 | 7/1961 | Elsken | 340/208 X |
| 3,008,666 | 11/1961 | Kuck | 325/113 X |
| 3,158,027 | 11/1964 | Kibler | 340/224 X |
| 3,298,430 | 1/1967 | Kodaira | 219/388 X |
| 3,333,476 | 8/1967 | Hardy et al. | 73/362 R |


*Primary Examiner*—Bernard A. Gilheany
*Assistant Examiner*—F. E. Bell
*Attorney*—Campbell, Harris and O'Rourke

[57] **ABSTRACT**


A portable system for measuring a condition, particularly temperature, and indicating this measurement at a remote location. A portable insulating and protective container adapted for use in extreme temperature environments, such as occasioned within a furnace or oven, houses a small transmitter. The transmitter is connected to a transducer responsive to the condition to produce a signal that is transmitted to a remote receiving and monitoring location.


**9 Claims, 8 Drawing Figures**



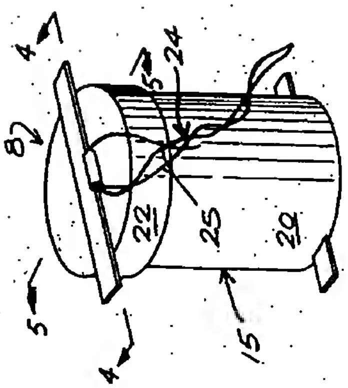
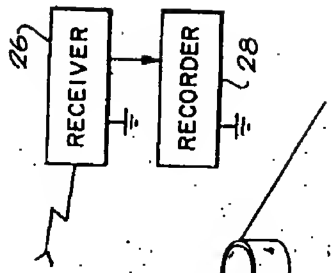



FIG. 2



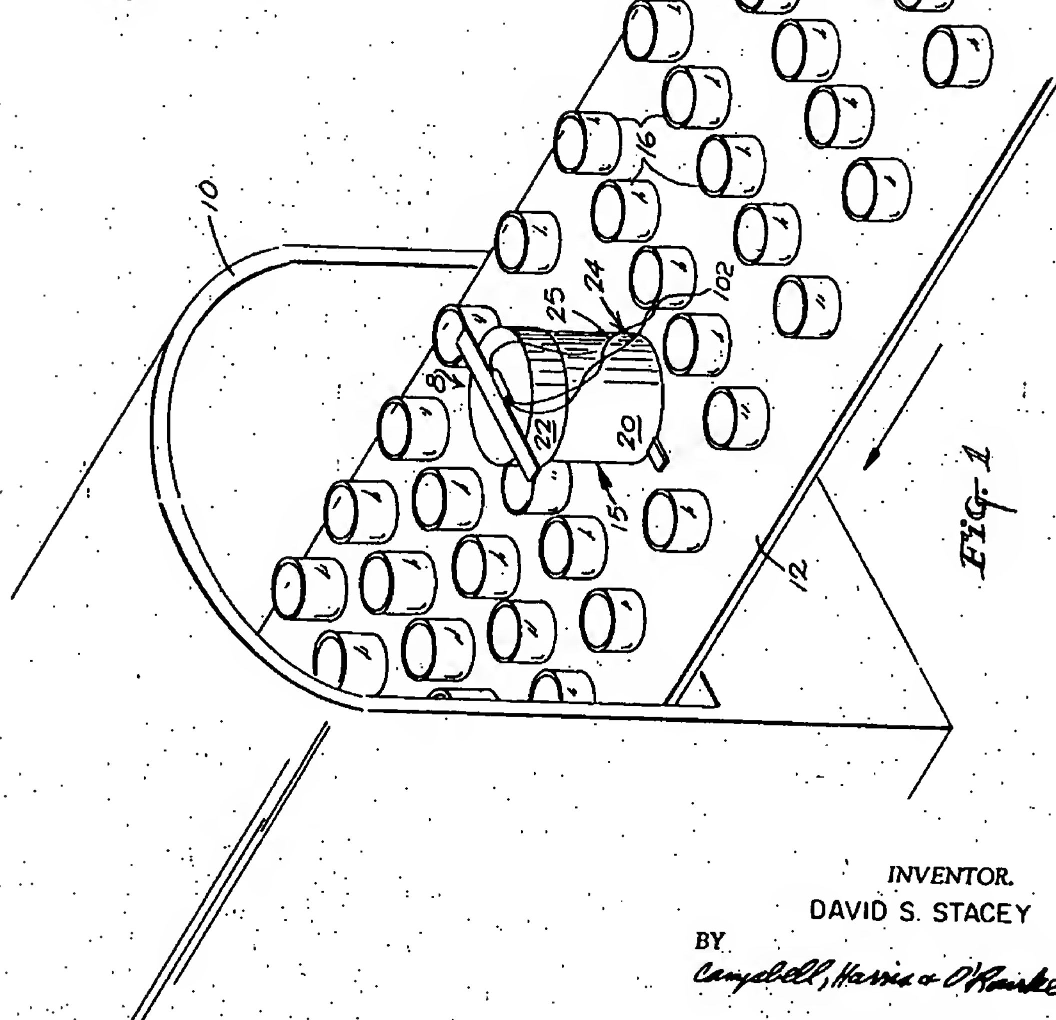




FIG. 1

INVENTOR.
DAVID S. STACEY
BY
Campbell, Harris & O'Rourke
ATTORNEYS

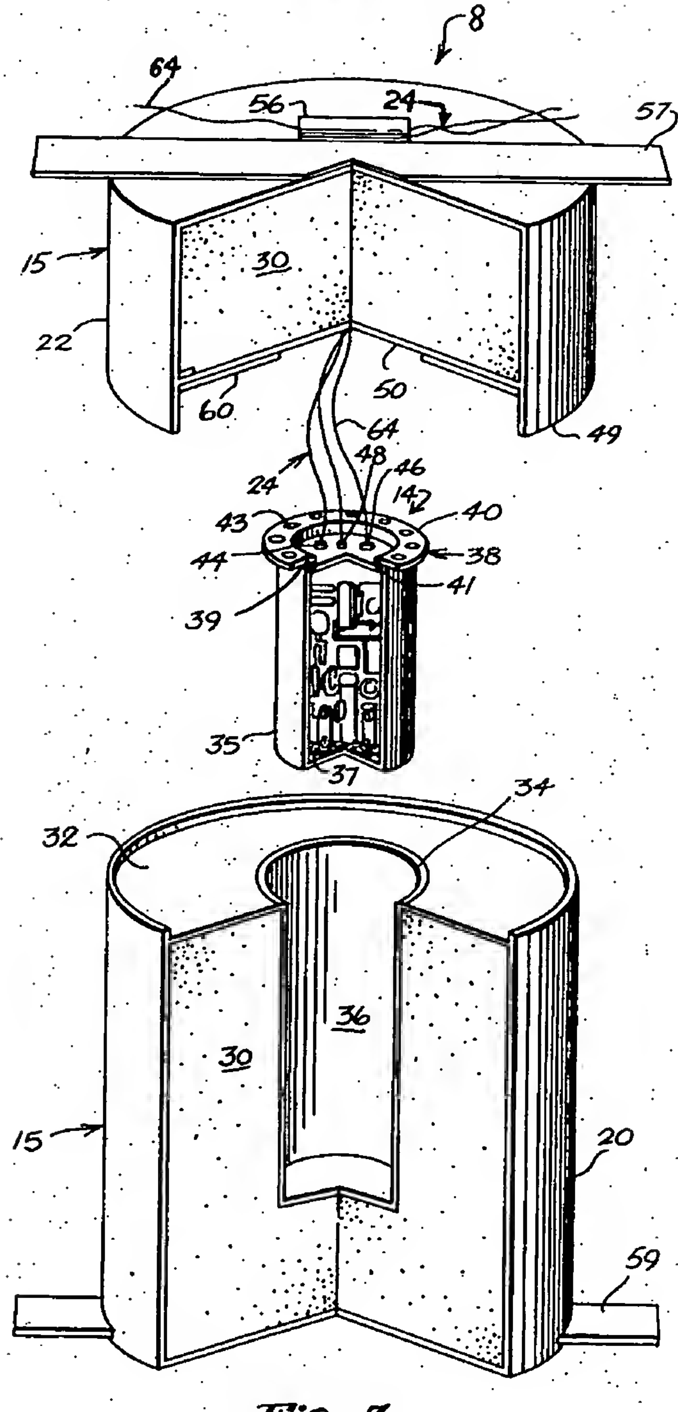



FIG. 3

INVENTOR:
DAVID S. STACEY

BY
Campbell, Harris & O'Rourke
ATTORNEYS

PATENTED JAN 25 1972 3,637,985

SHEET 3 OF 4

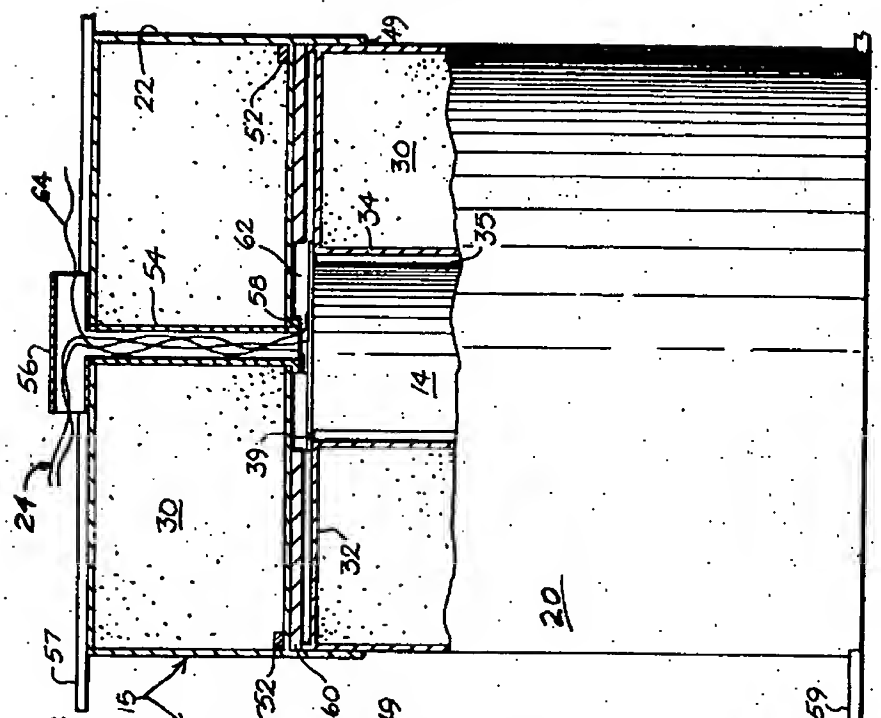



FIG. 4

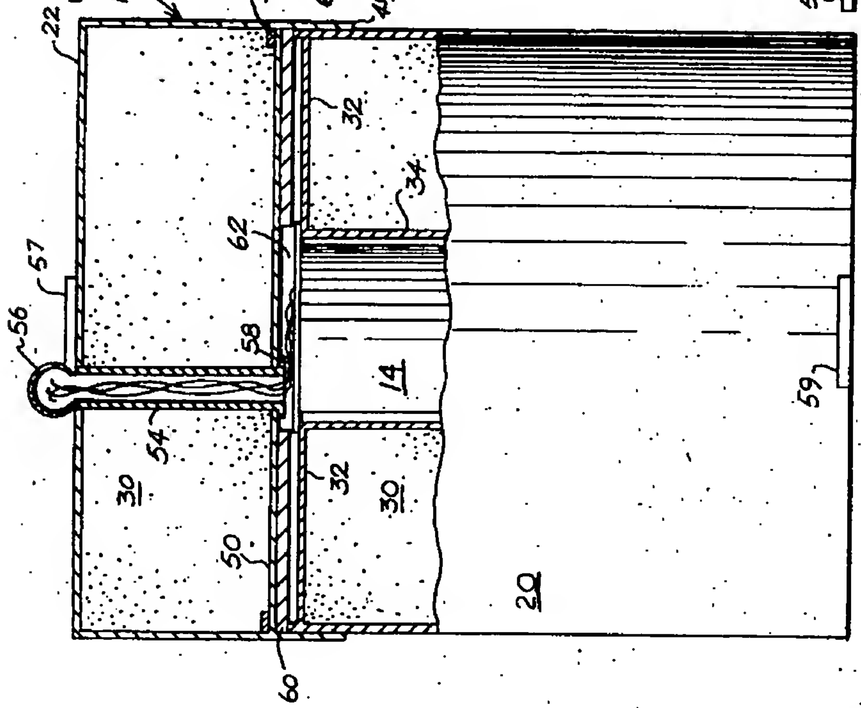


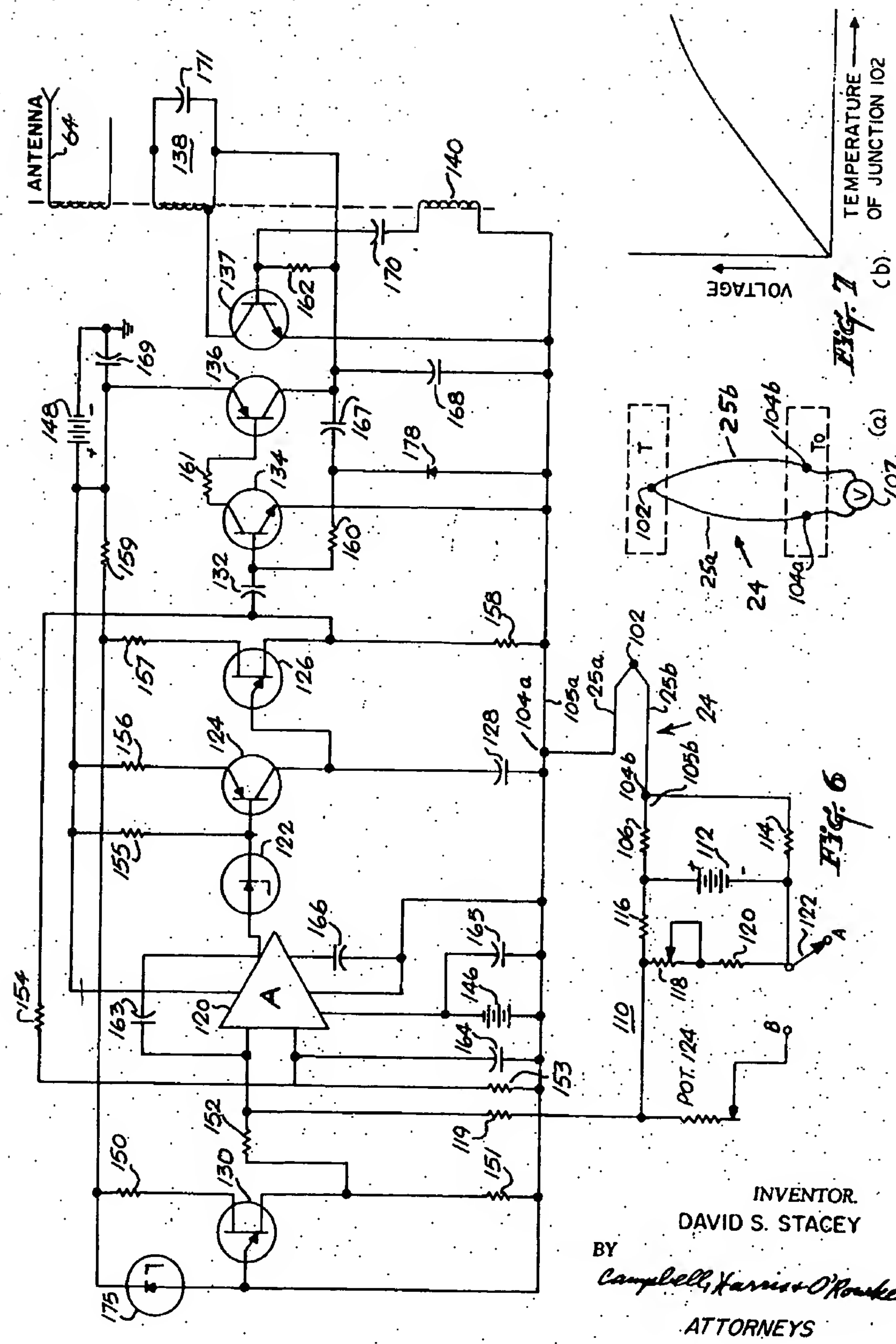

FIG. 5

INVENTOR.
DAVID S. STACEY

BY

Campbell, Harris & O'Rourke

ATTORNEYS




INVENTOR.
DAVID S. STACEY

BY

Campbell, Harris & O'Rourke

ATTORNEYS

# PORTABLE REMOTE LOCATION MEASURING SYSTEM

## BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a remotely located condition measuring system and particularly to a portable system for use in an oven to generate temperature indicative signals and to transmit these signals.

2. Description of the Prior Art

It is often necessary to determine the existence and magnitude of a condition at a remote location. This is particularly true, for example, in the maintenance of temperature conditions in glass production wherein glassware, such as containers, tubing, or glass sheets and the like, is formed at relatively high temperatures and is thereafter annealed or heat-treated down to room temperatures.

It is well recognized that the range of temperatures for optimum annealing of glassware is relatively small and, as annealing time is decreased in the interest of manufacturing efficiency without sacrificing favorable physical and chemical properties of the glass product, temperature regulation becomes even more critical. Often, the temperature of glassware within the oven, known as a lehr, must be controlled within a tolerance of plus or minus 50° F. in order to achieve optimum annealing; hence, it is important that the glassware temperature be closely monitored as the ware travels through the annealing lehr or oven. In this manner, better regulation of the temperature in the oven can be achieved which results, of course, in better regulation of glassware temperatures.

While apparatus for temperature measurement within an oven or furnace, including optical or radiation pyrometers, electronic pyrometers and thermocouples, have heretofore been known and/or utilized, none of these devices have proved to be completely successful. A major problem with the optical pyrometer, which measures the intensity of radiation by an incandescent body, is that the hot gases contained in the medium about the body interfere with the readings. As is well known, temperature responsive electronic devices, such as thermistors, are not practical at the high temperatures encountered in the first stages of a glass-annealing process.

While the thermocouple overcomes many of the disadvantages of other prior art devices, it has not proved to be completely successful due at least partially to bulkiness and a requirement for associated usage of unwieldly equipment, particularly where long oven usage was contemplated. More specifically, if the thermocouple is to travel with the ware riding on a belt through the annealing oven, wire conductors have heretofore been necessary in order to conduct the electrical signal from the thermocouple to a temperature meter or recorder outside the oven for prompt indication. Beside being cumbersome, the added effective resistance of the wires subjected to varying oven temperatures tended to introduce errors which often made the obtained readings so inaccurate as to be unreliable.

The present invention is an improvement over such temperature measurement systems of the prior art; yet, the invention permits the use of a relatively inexpensive sensor such as a calibrated thermocouple for the measurement. The apparatus includes a portable transmitting unit which is impervious to contemplated adverse conditions to be encountered; also, the unit is small enough to travel through an annealing oven with the ware and requires no associated cumbersome equipment or connecting wires to generate a condition indicating signal and conduct the same outside the oven for utilization.

The portable unit includes a transmitter responsive to the magnitude of the signal from a transducer, such as a thermocouple utilized in the measurement of temperature, to radiate signals suitable for immediate conversion outside of the oven to a temperature indicator that accurately reflects the temperature sensed within the oven. The unit further includes, in order to protect the electrical components of the transmitter, an insulating container adapted to receive the transmitter for protecting it against high temperatures encountered within the oven.

## SUMMARY OF THE INVENTION

The invention enables accurate and remote monitoring of a condition. It is particularly useful for measurement of extreme temperature conditions such as may be encountered in a glass-annealing oven. Further, the invention enables accurate temperature measurement in changing environments which are displaced one from the other and from the monitoring location.

Thus, it is an object of the present invention to provide a novel portable sensing system for the indication of a condition existing at a remote location from the condition monitoring location.

It is another object of the invention to provide a wireless sensing system for the measurement of a condition and the indication of the condition at a remote location.

It is a further object of the invention to provide a portable measuring apparatus which may be operated in a high temperature environment such as occasioned within an oven or furnace.

A further object of the invention is to provide a transmitting unit operative within a high temperature environment to produce and transmit signals indicative of a condition such as temperature within the environment.

A further object of the present invention is to provide a portable temperature sensing system having a calibrated thermocouple transducer responsive to temperature, and a temperature compensation network to automatically produce a signal to compensate for the change in the reference junction temperature of the thermocouple from the reference junction calibration temperature thereof.

Another object of the invention is to provide an insulating container for housing and protecting a transmitter from extreme environmental conditions outside the container.

It is a further object of the invention to provide a portable temperature sensing system having the contained transmitter sensing system having the contained transmitter responsive to a transducer signal, and an adjustable temperature compensation network to provide a signal to compensate for parameter changes of the transmitter due to temperature changes thereof from a predetermined reference temperature.

These and other objects and advantages will be apparent to those skilled in the art from the following description of a preferred embodiment of the invention as shown in the accompanying drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of the measuring apparatus of the invention shown in conjunction with an annealing lehr to sense temperatures within said lehr;

FIG. 2 is a perspective view of the portable measuring apparatus shown in FIG. 1;

FIG. 3 is an exploded perspective view of the transmitting unit with a portion cutaway for illustrative purposes;

FIG. 4 is a side sectional view of the container taken along the lines 4—4 of FIG. 2;

FIG. 5 is a view similar to FIG. 4 but taken along the lines 5—5 of FIG. 2;

FIG. 6 is a schematic circuit diagram of the transmitter shown in FIG. 3; and

FIGS. 7*a* and 7*b* are a circuit and graph, respectively, to illustrate the manner of calibration of the thermocouple.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, a preferred embodiment of the measurement apparatus 8 of the system for use in a high-temperature environment is shown positioned to travel through an oven or furnace 10 on a conveyor belt 12 in the direction as indicated by the arrow. Measuring apparatus 8 includes a transmitting unit 14 (as shown in FIG. 3) positioned within an insulating container 15 of a material such as steel, for example, and is provided to generate a signal indicative of temperature, such as the temperature of one of the glass jars 16. Mea-

suring apparatus 8 and jars 16 are positioned on the conveyor belt 12 so as to permit travel through the oven at a fixed distance one from the other. Measurement apparatus 8 includes, as shown best in FIGS. 2 and 3, the insulating container 15 having a base member shown in the drawings as a metal cylindrical can 20 and a metal cover member 22 also cylindrical in shape and adapted to tightly fit onto the can 20.

A thermocouple 24 is attached to the surface of a jar 16 by any conventional means such as by a tape or by a suitable temperature-resistant bonding adhesive. The temperature of the particular jar 16 is sensed by the thermocouple 24 and the corresponding signal conducted through wires 25 to the transmitting unit 14. The temperature signal is thereupon processed as more fully hereinafter described with reference to FIG. 6 and a corresponding radiant energy signal is transmitted out of the oven 10 to a receiver 26, preferably located outside the oven, the output signal from which receiver may be immediately indicated by a temperature meter (not shown) and/or permanently recorded on a time-temperature recorder 28.

Although a thermocouple for producing a signal corresponding to temperature is shown, it should be readily apparent that other transducers might be substituted to detect other conditions; for example, a stain gage to detect thermal expansion or contraction of an article such as one of the jars 16. In addition, it is to be appreciated that the transmitted signal could be an environmental signal within the oven in which case the transducer may be detached from any article traveling through an oven 10.

Referring particularly to FIG. 3, there is shown a disassembled cutaway portion of the measurement apparatus 8. THe can 20 is partially filled with an insulating powder 30 up to a refractory ring-shaped plate 32 and about a cylindrical cup 34 concentrically positioned within can 20 and held in place by the plate 32 and generally by the powder 30. Transmitter 14 is received and confined within a cavity 36 defined by the cup 34. The electrical elements of the transmitter are received in a casing, or can, 35 and are mounted on a rectangular circuit block 37 attached at one end to a base 38. In an embodiment constructed in accordance with the invention, can 35 and base 38 were also made of steel. Base 38 is essentially disc-shaped with a central portion closing the interior of the can 35 and having a shoulder 39 terminating in peripheral flange 40. Shoulder 39 extends downwardly from flange 40 and has an O-ring 41 mounted thereon to seal the can 35. Flange 40, which has a plurality of holes 41 when transmitter 14 is received within the cavity 36 so as to longitudinally position the transmitter within the cup 34.

The cylindrical casing, or can, 35 has a diameter smaller than the inner diameter of the cup 34 so as to define a space between respective walls thereof when the transmitter 14 is positioned within cavity 36, which space opens to holes 43 in flange 40. The central portion of base 38 has three openings therein to receive insulated terminals 44 and 46, and a ground terminal 48, which terminals are connected with the electrical components within the casing 35 as more fully hereinafter described with reference to FIG. 6.

Referring to FIGS. 3, 4, and 5, the cover member 22 has an outer cylindrical wall 49 slightly larger in diameter than can 20 so that the lower portion of wall 49 receives the upper portion of the can 20 therebetween. Cover member 22 is also filled with the insulating powder 30 but is contained by a refractory ring-shaped plate 50 positioned inwardly from the lower end and having a shoulder 52 at the inner wall of the cover member. Cover member 22 is provided with a longitudinally extending tube 54 opening at one end to a laterally extending chimney hood 56 suitably welded to the top of the cover member 22, and opening at the other end through plate 50 to the interior of can 20. A nut 58 is threadably engaged on the end of tube 54 adjacent to plate 50 to support the plate. As shown in FIG. 5, the passageway formed by the tube 54 extending through the cover 22 is offset from center; nevertheless, it should be apparent that exact positioning of the tube is not critical so long as tube 54 communicates with cup 34. Removal of the cover 22 from can 20 is facilitated by bars, or handles, 57 and 59 attached to the cover and can, respectively.

A ring 60 of a size sufficient to substantially bridge the area between the sidewall of can 20 and cup 34 is bonded to the plate 50 in order to facilitate positioning of cover 22. Thus, when the cover is in position on can 20, a cavity 62 is formed providing a passageway between tube 54 and the holes 43 in flange 40 and the passageway through tube 54. Since the cylindrical casing 35 of transmitter 14 has a diameter smaller than the diameter of the cup 34, a liquid may be contained within the cup 34 about and under the casing 35. Therefore, a liquid heated to its boiling point in the oven or furnace environment may escape in vapor form through holes 43 into the cavity 62 and through the passageway formed by tube 54 and out to the oven or furnace. The vapor or steam may also circulate in the cavity 62 between the ring 60 and plate 32.

The provision for the containment of a liquid, such as water, about the casing 35 insures that when heat is conducted through the thick layer of insulating powder 30 the casing 35 will reach at a maximum temperature only the boiling point temperature of the liquid contained. Of course, after the liquid is depleted, the casing 35 could reach a higher temperature and, hence, if the transmitter utilized cannot tolerate elevated temperature, then a sufficient supply of liquid must be assured for the operation time contemplated. If the transmitter can withstand elevated temperatures, then, of course, it is not mandatory that a liquid be used, although it might prove advantageous for more uniform results even in this latter case.

It is obvious that the general dimensions of the measurement apparatus 8, and more specifically the thickness of the layer of powder 30, and width of cup 34 may be varied depending on contemplated usage to maintain suitable transmitter temperature. The embodiment shown was built and tested for use at temperatures exceeding 1,000° F. for at least 15 minutes, and found to be satisfactory for use in conjunction with a glass annealing process.

The wires 25 of the thermocouples 24 attached to one of the glass jars 16 may be inserted through chimney hood 56, through tube 54, and connected to the insulated input terminal 44 and ground terminal 48 of the transmitter. Further, an antenna 64 from the transmitter 14 may be connected to the terminal 46 and also extend in the assembled position of the measurement apparatus 8 through the tube 54 and out of the cover member 22. Since the wave propagation distance out of the annealing oven 10 from the apparatus 8 is generally relatively short, suitable transmission may be effected, for example, by positioning a simple wire antenna outside the cover member 22.

Referring to FIG. 6, transmitter 14 receives a direct current input signal from thermocouple 24 through wires 25 which signal is indicative of the magnitude of the temperature at the surface of the particular glass jar 16 to which the thermocouple is secured. The thermocouple 24 is of a conventional type, such as iron-constantan, suitable for use over wide temperature ranges.

The thermocouple 24 is attached to the surface of the glassware, or jar, 16 at a measuring junction 102. Conductor 25*a* of one type metal, such as iron, is connected to a reference, or cold, junction 104*a*; and conductor 25*b* of another type metal, such as constantan, is connected to a reference, or cold, junction 104*b*. The junctions 104*a* and 104*b* may represent the connections of thermocouple 24 to transmitter 14 at the input and ground terminals 44 and 48, respectively, and which connections are made within can 20 with conductors 105*a* and 105*b*. Preferably, the metal conductors 105 of the circuit are copper. Therefore, a thermoelectric effect may also be developed across each junction 104 although the junctions are at substantially the same temperature.

The thermocouple having effectively three junctions may be calibrated in conventional manner as more particularly illustrated with reference to FIG. 7. FIG. 7*a* illustrates that the

thermocouple 24 may be calibrated with the reference junctions 104 at a constant temperature ($T_0$), which is normally 32° F., the melting point of ice, to produce a voltage (V) measured by a meter 107 as a function of the temperature (T) of the measuring junction 102. A curve illustrating this relation may be drawn and is shown in FIG. 7*b*. It is well known that if the reference junctions of a three-junction thermocouple are maintained equal to each other but above the temperature at which the reference junctions are maintained during calibration (the new temperature being indicated by $T_1$), the indicated reading upon measurement is reduced and must be corrected. The correction is simply the voltage produced when the reference junctions are at temperature $T_0$ and the measuring junction at temperature $T_1$. The thermocouple relation may be expressed as follows:

$$^{E}T_0 \rightarrow T = {}^{E}T_0 \rightarrow T_1 + {}^{E}T_1 \rightarrow T \qquad (1)$$

where as already explained, $T_0$ is the reference junction calibration temperature, $T_1$ is a new reference junction temperature, and T is the measuring junction temperature.

In the present invention there is accordingly provided a sensistor 106 of conventional type and having a predetermined resistance change characteristic as a function of temperature to compensate for temperature variations of the reference junction 104 from the calibration temperature. Sensistor 106 is connected in a voltage dividing compensation network 110 so as to compensate the input signal by a voltage which varies with temperature approximately the same as the voltage variance across junction 102 as a function of temperature difference from the reference junction temperature. In this manner, a corrected emf is produced which includes $^{E}T_0 \quad T_1$ to automatically compensate for the signal change due to the actual reference junction temperature being different from the reference junction temperature at which the thermocouple 24 is calibrated. As an example, if the reference junctions 104 were at the boiling point of water and the measuring junction 102 was at a higher temperature, the compensation voltage to be added to a thermocouple previously calibrated with the reference junction at 32° F. and to be produced by sensistor 106 would be the voltage produced by the thermocouple when the reference junctions 104 are at 32° F. and the measuring junction 102 is at the boiling point of water.

If water is used as the liquid in tube 34 about the transmitter 14, the temperature of the reference junctions 104*a* and 104*b* at terminals 44 and 48, respectively, will often be at substantially the boiling point of the water after sustained travel of unit 14 through the high temperature oven 10 whereupon the steam fills cavity 62 adjacent the terminals 44 and 48, and which steam escapes through tube 54.

The uncompensated thermocouple signal from measuring junction 102 is conducted between junctions 104*a* and 104*b* at the input terminal 44 and ground terminal 48, respectively, to the compensation network 110. The network 110 connected to terminal 44 includes the sensistor 106 connected to the positive electrode of a battery 112, and a resistor 114 connected to the negative electrode of battery 112. A resistor 116 is connected between sensistor 106 and battery 112 to a potentiometer 118 serially connected to a resistor 120 leading also to the negative electrode of battery 112. A switch 122 is further connected to the negative electrode of battery 112 and is open at position A as shown or may be closed in position B with the wiper arm of a potentiometer 124, the opposite end of which potentiometer is connected between the resistors 116 and 118 and to a resistor 119.

The sensistor 106 and resistor 116 have a substantially low resistance in comparison to the other resistors of the compensation network and may be considered as the only path of network 110 conductive of the signal from thermocouple 24. It is readily apparent that the direct current voltage drop across sensistor 106 at a given temperature and across resistor 116 may be initially set by the adjustment of the resistance values of potentiometer 118 and/or potentiometer 124 when switch 122 is in position B. Potentiometer 124 may be adjusted according to the different ranges of operation of thermocouple 24. The voltage drop across sensistor 106 thereafter is a function of temperature corresponding to the compensation voltage.

The voltage-dividing network 110 may be utilized also to compensate for the approximated change in the thermocouple signal as processed due to minor changes or circuit parameters incurred with increased temperature of the transmitter 14. More specifically, the resistance of potentiometer 118 may be varied to change the current from battery 112 through one leg having resistors 116, 118, and 120, with respect to the other leg in parallel with the one leg, and including sensistor 106 and resistor 114. Further, when switch 122 is in position B, the potentiometer 124 is in parallel with potentiometer 118 and resistor 120. The relative resistance of the current paths from battery 112 may thus be adjusted so as to further regulate the current through and, therefore, the initial voltage drop across resistor 116 with respect to the current through and the voltage drop across sensistor 106.

The thermocouple signal, as particularly compensated in accordance with the reference junction temperature during use from the reference junction calibration temperature, is conducted through resistor 119 to an inverting input of a direct current operational amplifier 120 of conventional type, such as the "$\eta a$ 702 **Monolithic Operational Amplifier" particularly suitable for amplification of transducer outputs, and sold by Fairchild Semiconductor (a Division of Fairchild Camera)**, 313 Fairchild Drive, Mountain View, California.

The output of amplifier 120, conducted through a Zener diode 122 which establishes a reference voltage level, controls the current through a PNP-type resistor 124. A unijunction transistor 126 produces an oscillating signal at a frequency determined by the charging current to a capacitor 128. The output of unijunction transistor 126 is an audio signal of frequency proportional to the voltage at the collector of transistor 124. The current in resistor 158 is accurately proportional to the frequency and is fed back to the noninverting input of amplifier 120 to form a highly stable voltage-to-frequency converter. A second unijunction transistor 130 is provided in order to compensate for direct current drifts of the unijunction transistor 126.

The audiofrequency signal, in the form of a pulse of short duration, is coupled through a direct current blocking capacitor 132 to a pulse shaper which may be of monostable multivibrator type which includes NPN-transistor 134 and PNP-transistor 136. The output from the pulse shaper is a series of "stretched" pulses in phase and frequency with the audio signal from unijunction transistor 126. An oscillator, which includes transistor 137, produces a radiofrequency carrier signal which is amplitude modulated by the pulses at the audio signal frequency. The feedback path of the oscillator includes an inductor of a parallel tank circuit 138 which is tapped and connected to the base of transistor 137 and is also magnetically coupled to an inductor 140 connected between the base of transistor 137 and ground. Upon conduction of transistor 137, the current induced in inductor 140 in one direction drives the base more negative and below cutoff rendering the transistor 137 nonconductive. The breakdown of the field about the inductor in tank 138 induces a current in the opposite direction in inductor 140 thereby immediately rendering the base of transistor 137 positive beyond cutoff. The cycle repeats and transistor 137 sustains oscillation, and as modulated by the audio signal from transistor 136 the carrier signal is radiated from the antenna 64 magnetically coupled to the inductor of the tank circuit 138.

With good conduction in a lehr oven which typically may measure about 7 feet wide, the oven will act as a waveguide and cut off spurious signals with a half wavelength longer than the width of the oven. The cutoff signals would be at a frequency of approximately 70 ml./s. and less in the typical lehr oven mentioned. However, operation with carrier signals having a greater half wavelength than the width of the oven

may often be desirable. It has been found suitable in this instance to feed a pickup wire (not shown) through the oven 10 and to anchor this wire to the sides of the oven.

The power or supply voltage source for the transmitting unit 14 is supplied from batteries 146 and 148 which are also mounted on the circuit board block 37 contained within the cylindrical casing 35 and are of a type such as those known as "mercury batteries" which have been found suitable for operation at temperatures in the area of boiling point of water. Further, silicon-type semiconductors were utilized in the transmitter for operation at such temperatures.

For purposes of example, the following lists the identifying types and/or parameters of elements, in addition to those already mentioned, utilized in a particular tested embodiment of the transmitter 14:

| Resistors | Parameter | Capacitors | Parameter |
|---|---|---|---|
| | (ohms) | | (farads) |
| 106 (sensistor) | 100 | 128 | $10^{-8}$ |
| 114 | 20.5 K | 132 | $5(10^{-10})$ |
| 116 | 100 | 163 | $10^{-7}$ |
| 118 (potent.) | 5 K | 164 | $10^{-7}$ |
| 119 | 576 | 165 | $10^{-7}$ |
| 120 | 20 K | 166 | $10^{-7}$ |
| 124 (potent.) | 17.2 K | 167 | $10^{-8}$ |
| 150 | 649 | 168 | $10^{-8}$ |
| 151 | 120 | 169 | $10^{-7}$ |
| 152 | 2.57 K | 170 | $5(10^{-10})$ |
| 153 | 1.3 K | 171 | $10^{-10}$ |
| 154 | 4.25 K | | |
| 155 | 4.75 K | Diodes | Type |
| 156 | 100 | | |
| 157 | 649 | 122 | 1N755 |
| 158 | 100 | 175 | FA8004 |
| 159 | 240 | 178 | 1N3605 |
| 160 | 7.5 K | | |
| 161 | 15.8 K | Transistors | |
| 162 | 61.9 | | |
| | | 124 | 2N3638 |
| | | 126 | 2N2647 |
| | | 130 | 2N2647 |
| | | 134 | 2N3565 |
| | | 136 | 2N3638 |
| | | 137 | 2N3641 |

Although only one embodiment of the invention has been illustrated and described, it is anticipated that various changes and modifications will be apparent to those skilled in the art, and that such may be made without departing from the scope of the invention as defined by the following claims.

I claim:

1. A system for monitoring a condition within an oven, the condition existing within the oven at a location remote from the monitoring location, the system comprising:
a transducer for producing a signal indicative of the condition sensed within an oven;
means for transmitting an electromagnetic energy signal corresponding to the transducer signal;
an insulated container for receiving said transmitting means, said insulated container including liquid means and vapor escape means for preventing the temperature within said container from rising beyond a predetermined temperature while in an oven;
means for receiving the transmitted signal; and
means for converting the received signals to indicate the condition sensed within the oven by said transducer.

2. The system as defined in claim 1 wherein:
said container has a cavity larger than said transmitting means and into which said cavity said transmitting means is received;
wherein said liquid means for preventing the temperature within said cavity from rising beyond a predetermined temperature is contained in the cavity about said transmitting means, and wherein said vapor escape means includes a passageway in said container and opening externally of said container from said cavity so that the liquid upon vaporization being able to escape through the passageway so as to maintain the immediate environment of said transmitting means at substantially the liquid temperature.

3. The system as defined in claim 1 wherein the transducer includes:
a calibrated thermocouple having a measuring junction and at least one reference junction; and
wherein the transmitting means includes:
an oscillator for producing a carrier signal;
compensating means including a sensistor for providing a signal to offset any error in the signal from the thermocouple due to temperature difference of the reference junction from a predetermined calibration temperature;
converting means for producing a pulse signal train having a frequency indicative of the amplitude of the compensated thermocouple signal;
an antenna coupled to said oscillator; and
means for insulating said converting means, said compensating means, said oscillator, and the reference junction of said thermocouple;
whereby the carrier signal may be modulated by the pulse signal train from said converting means and radiated by said antenna from within the oven to said receiving means.

4. A system for measuring a condition in an oven, the system comprising: a transducer for producing a signal indicative of the condition; an electronic unit for receiving the signal from said transducer; and an insulating container for the electronic unit including,
a base member,
thermal insulating means within said base member and defining a cavity which receives said electronic unit, said thermal-insulating means defining said cavity receiving liquid to surround said electronic unit received in said cavity, said container having vapor escape means so as to maintain the immediate electronic unit environment substantially at the liquid temperature; and
a cover member removably mated with said base member,
other thermal-insulating means within said cover member,
one of said thermal-insulating means defining a passageway extending from the cavity through the wall of the respective member,
whereby the transducer may be connected to the electronic unit through the passageway.

5. A system for monitoring the temperature of an article of manufacture traveling through a furnace, the system comprising:
a transducer within the furnace to travel with the article for producing a signal corresponding to the temperature of the article at successive locations in the furnace;
a transmitter for transmitting an electromagnetic energy signal corresponding to the transducer signal;
a portable insulated container to travel with the article, said container receiving and protecting said transmitter from adverse temperature conditions existing within the furnace;
said insulated container containing liquid about the transmitter and having a passageway extending from within and through said container,
whereby the liquid upon vaporization may escape from said container through the passageway so as to maintain the transmitter temperature at substantially the liquid temperature;
means for receiving the transmitted signals;
whereby the received signals are indicative of the temperature sensed by the transducer at successive locations within the furnace.

6. A system for monitoring an environmental condition at successive locations within an oven, the successive locations being remote from the monitoring location, the system comprising:
a transducer for producing a signal corresponding to the condition;

a transmitter for transmitting an electromagnetic energy signal corresponding to the transducer signal;

a portable insulated container receiving the transmitter, said container having a passageway extending from within and through said container, and said container containing liquid about said transmitter;

whereby the transmitter temperature may be maintained at substantially the liquid temperature to permit efficient transmitter operation within the furnace;

means for moving said transducer, transmitter and container through the oven; and

means for receiving the transmitted signals;

whereby the transmitted signal may be received outside the oven from the remote locations of the sensed environmental condition.

7. A method of protecting a transmitter traveling through an oven, the steps comprising:

sealing the transmitter in a liquidproof container;

immersing the sealed transmitter in a contained liquid medium;

enclosing the sealed transmitter in the contained liquid medium within an insulating container; and

conducting the contained liquid in vapor form out of the insulating container.



8. A method of maintaining a reference junction of a thermocouple transducer traveling through a heat treating oven below a predetermined temperature within the oven, the steps comprising:

positioning the reference junction of the thermocouple in a liquid environment;

insulating the reference junction of the thermocouple and the liquid environment; and

conducting the contained liquid in vapor form out of the insulating container;

whereby the reference junction may be substantially maintained below the predetermined temperature corresponding to the boiling point temperature of the liquid contained.

9. An assembly for sensing a condition within an oven comprising: an insulated container defining therein a cavity of predetermined size; sensing means for producing a signal indicative of the condition sensed within the oven, at least a portion of said sensing means being positioned within said cavity, said portion being smaller in size than said cavity; and a liquid contained within said cavity and vapor escape means for preventing the temperature within said cavity from rising beyond a predetermined temperature.

* * * * *

US-PAT-NO: 5391862

DOCUMENT-IDENTIFIER: US 5391862 A

TITLE: Induction heating system for a near net shaped gear blank

---------- KWIC ---------

Claims Text - CLTX (29):

signal processor means coupled to said **temperature** sensing means for **recording** a plurality of **temperatures** of the workpiece as it rotates within the heating zone;

Claims Text - CLTX (30):

said computer means responsive to operation of said signal processor means for calculating an average **temperature** of the workpiece from the plurality of **temperatures** sensed and **recorded** and for deenergizing said induction heater when the average **temperatures** calculated reach predetermined values.

Claims Text - CLTX (32):

signal processor means coupled to said **temperature** sensing means for **recording** for each tooth of the workpiece **temperatures** at one or more locations including the top, root, and flank thereof; and

US005391862A

# United States Patent [19]

**Amateau et al.**

[11] **Patent Number: 5,391,862**

[45] **Date f Patent: Feb. 21, 1995**

[54] **INDUCTION HEATING SYSTEM FOR A NEAR NET SHAPED GEAR BLANK**

[75] Inventors: **Maurice F. Amateau; G. Dwayne Kidwell; Nagesh Sonti,** all of State College, Pa.

[73] Assignee: **The Penn State Research Foundation,** University Park, Pa.

[21] Appl. No.: **6,901**

[22] Filed: **Jan. 21, 1993**

**Related U.S. Application Data**

[62] Division of Ser. No. 829,187, Jan. 31, 1992, Pat. No. 5,221,513.

[51] **Int. Cl.**[6] .............................................. **H05B 6/08**

[52] **U.S. Cl.** .................................. **219/667**; 219/640; 266/129

[58] **Field of Search** ............... 219/10.59, 10.57, 10.67, 219/10.77, 667, 640, 650; 148/573, 567; 266/129, 125, 87

[56] **References Cited**

U.S. PATENT DOCUMENTS

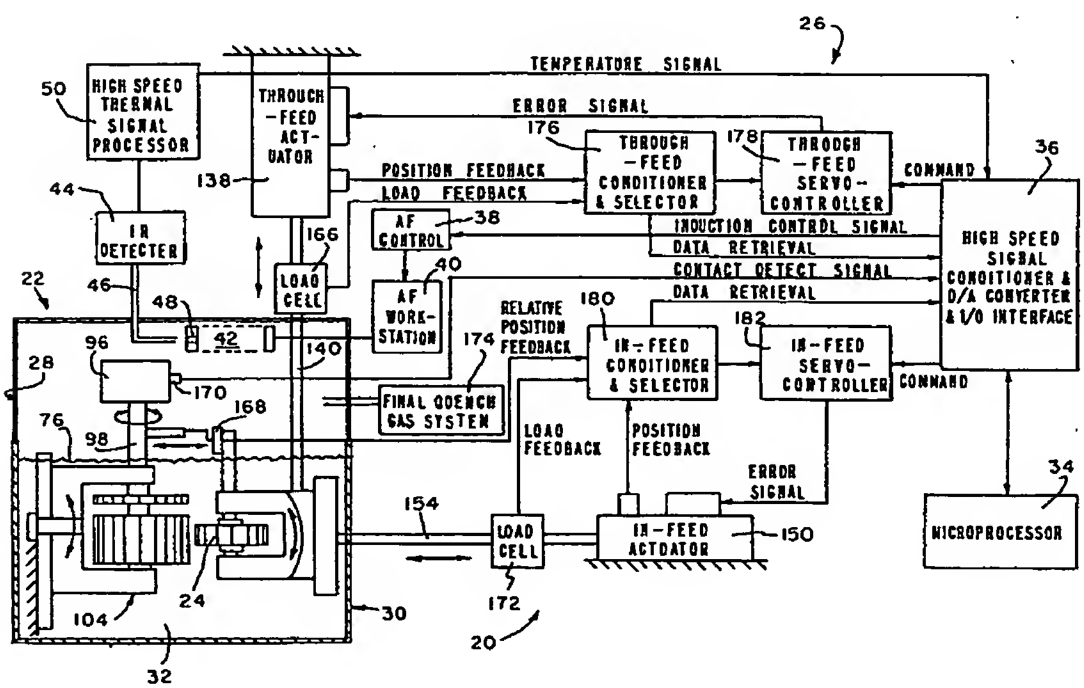
| | | | |
|---|---|---|---|
| 3,646,304 | 2/1972 | Dallet et al. | 219/615 |
| 4,675,488 | 6/1987 | Mucha et al. | 219/10.43 |
| 4,744,836 | 5/1988 | Pfaffmann | 148/150 |
| 4,845,328 | 7/1989 | Storm et al. | 219/10.59 |
| 4,894,501 | 1/1990 | Pfaffmann et al. | 219/10.59 |
| 5,055,648 | 10/1991 | Iecland et al. | 219/601 |

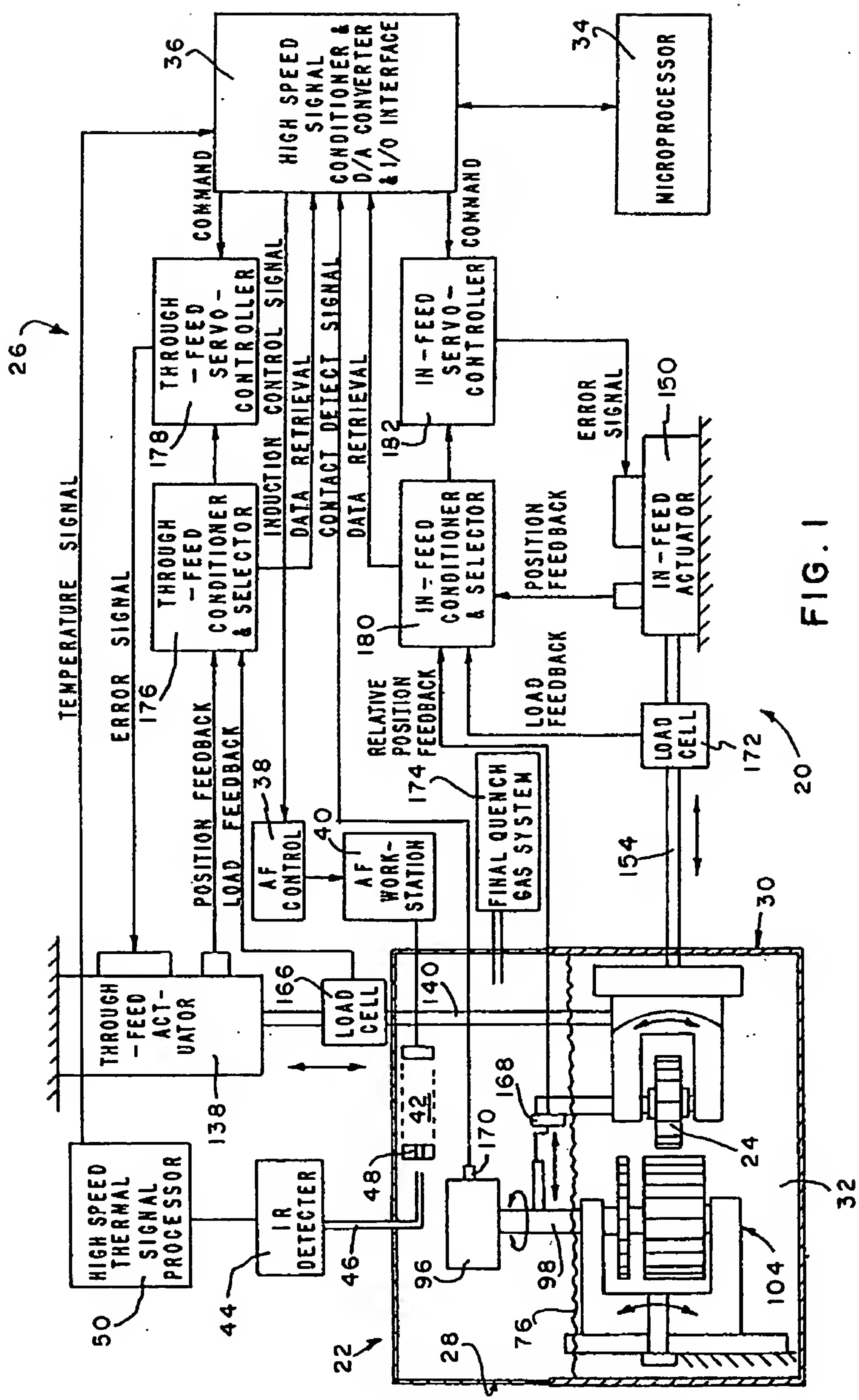
*Primary Examiner*—Philip H. Leung
*Attorney, Agent, or Firm*—Thomas J. Monahan

[57] **ABSTRACT**

An apparatus is disclosed for performing thermomechanical processing of gears in which precise control of the thermal, metallurgical and mechanical action during the forming process is maintained. The apparatus comprises an induction heating system which reaustenitizes the surface of the gear with minimum decarburization, a material transfer system which provides timely operations on the work piece, tooling and fixture adjustments which provide accurate initial conditions for forming, and a process control architecture that provides the precise sequence and timing necessary to achieve metallurgically sound and dimensionally accurate gears. Using this invention the induction heating cycle can be controlled from the peak, average or minimum gear surface temperature detected with a high response optical pyrometer. An inert environment is maintained around the workpiece during the induction heating and transfer to quenching above the $M_s$ temperature. Both through-feed and in-feed motion are simultaneously controlled by load, position and velocity transducers which provide feedback information to a supervising microprocessor. This apparatus produces metallurgically sound and accurate gears.

**15 Claims, 11 Drawing Sheets**




HIGH SPEED SIGNAL CONDITIONER & D/A CONVERTER & I/O INTERFACE
MICROPROCESSOR
COMMAND
COMMAND
THROUGH -FEED SERVO-CONTROLLER
IN-FEED SERVO-CONTROLLER
INDUCTION CONTROL SIGNAL
DATA RETRIEVAL
CONTACT DETECT SIGNAL
DATA RETRIEVAL
THROUGH -FEED CONDITIONER & SELECTOR
IN-FEED CONDITIONER & SELECTOR
TEMPERATURE SIGNAL
ERROR SIGNAL
ERROR SIGNAL
POSITION FEEDBACK
LOAD FEEDBACK
POSITION FEEDBACK
LOAD FEEDBACK
RELATIVE POSITION FEEDBACK
IN-FEED ACTUATOR
LOAD CELL
AF CONTROL
AF WORK-STATION
FINAL QUENCH GAS SYSTEM
THROUGH -FEED ACT-UATOR
LOAD CELL
HIGH SPEED THERMAL SIGNAL PROCESSOR
IR DETECTER
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
76
96
98
104
138
140
150
154
166
168
170
172
174
176
178
180
182
FIG. 1

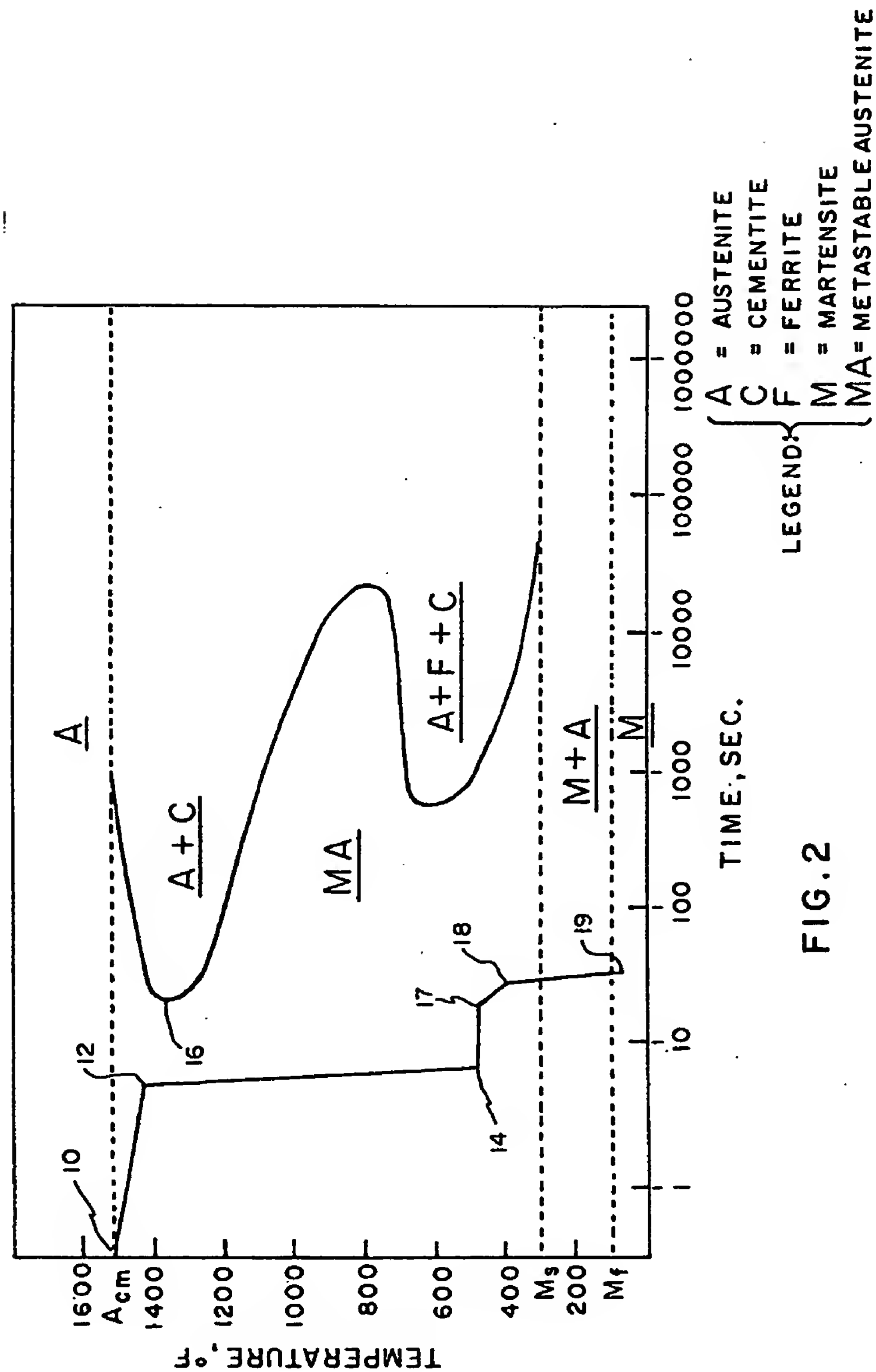

TEMPERATURE, °F
1600
$A_{cm}$
1400
1200
1000
800
600
400
$M_s$
200
$M_f$
TIME, SEC.
1
10
100
1000
10000
100000
1000000
A
A + C
MA
A+F+C
M+A
M
10
12
14
16
17
18
19
LEGEND:
A = AUSTENITE
C = CEMENTITE
F = FERRITE
M = MARTENSITE
MA = METASTABLE AUSTENITE

FIG. 2

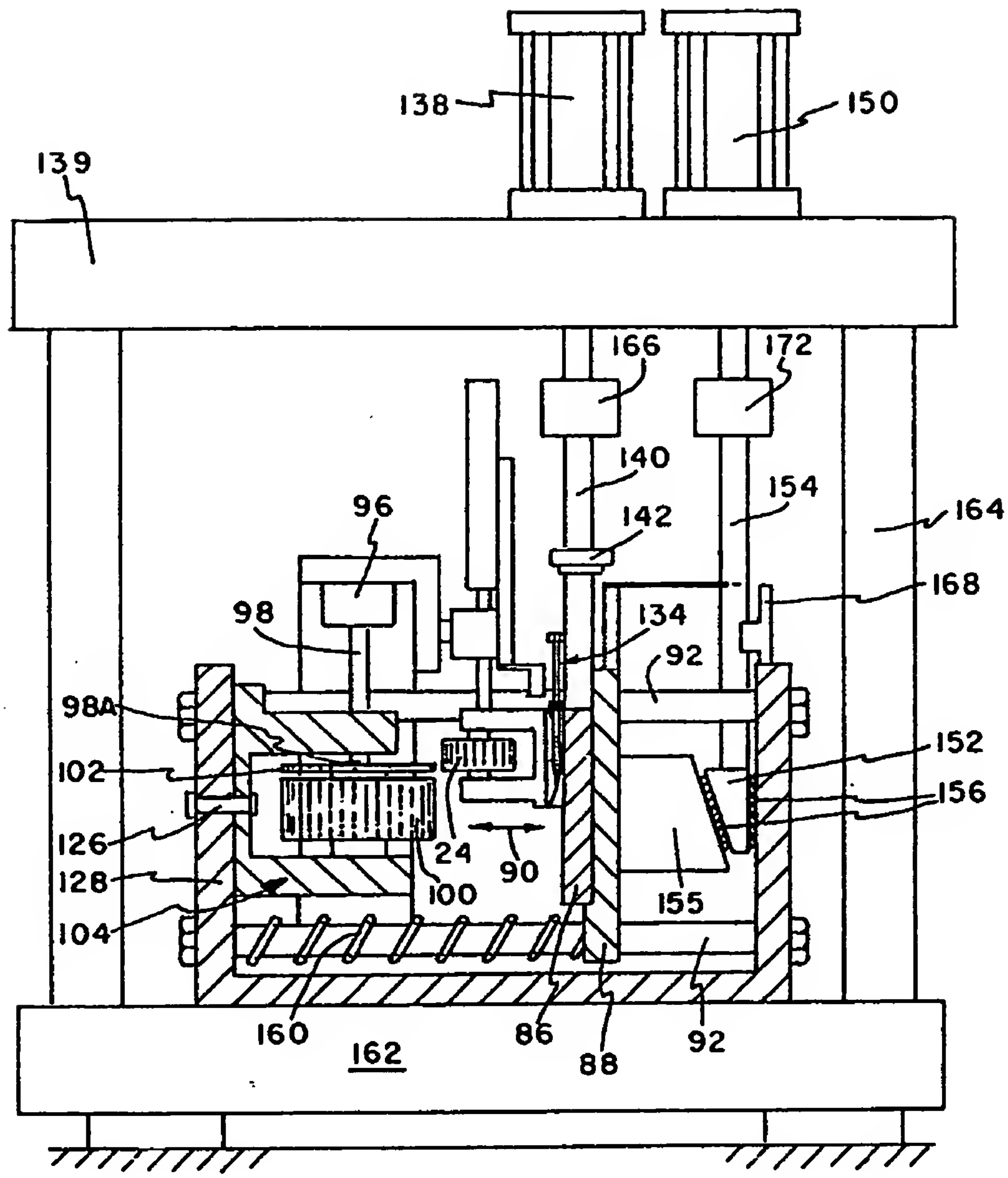

138
150
139
166
172
140
154
164
96
142
168
98
134
92
98A
102
152
156
126
24
90
128
100
155
104
160
86
88
92
162

FIG. 3

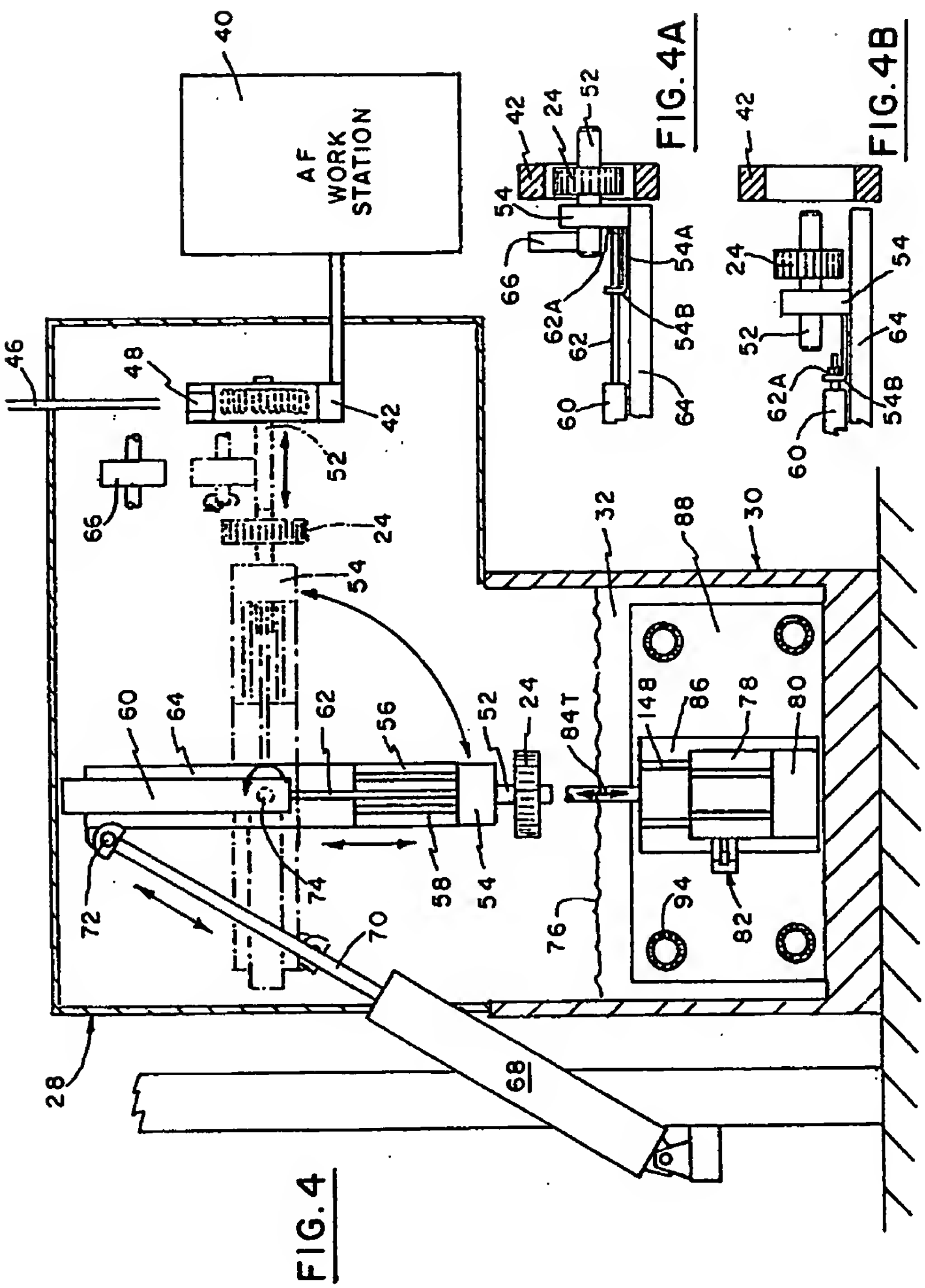



FIG. 4

FIG. 4A

FIG. 4B

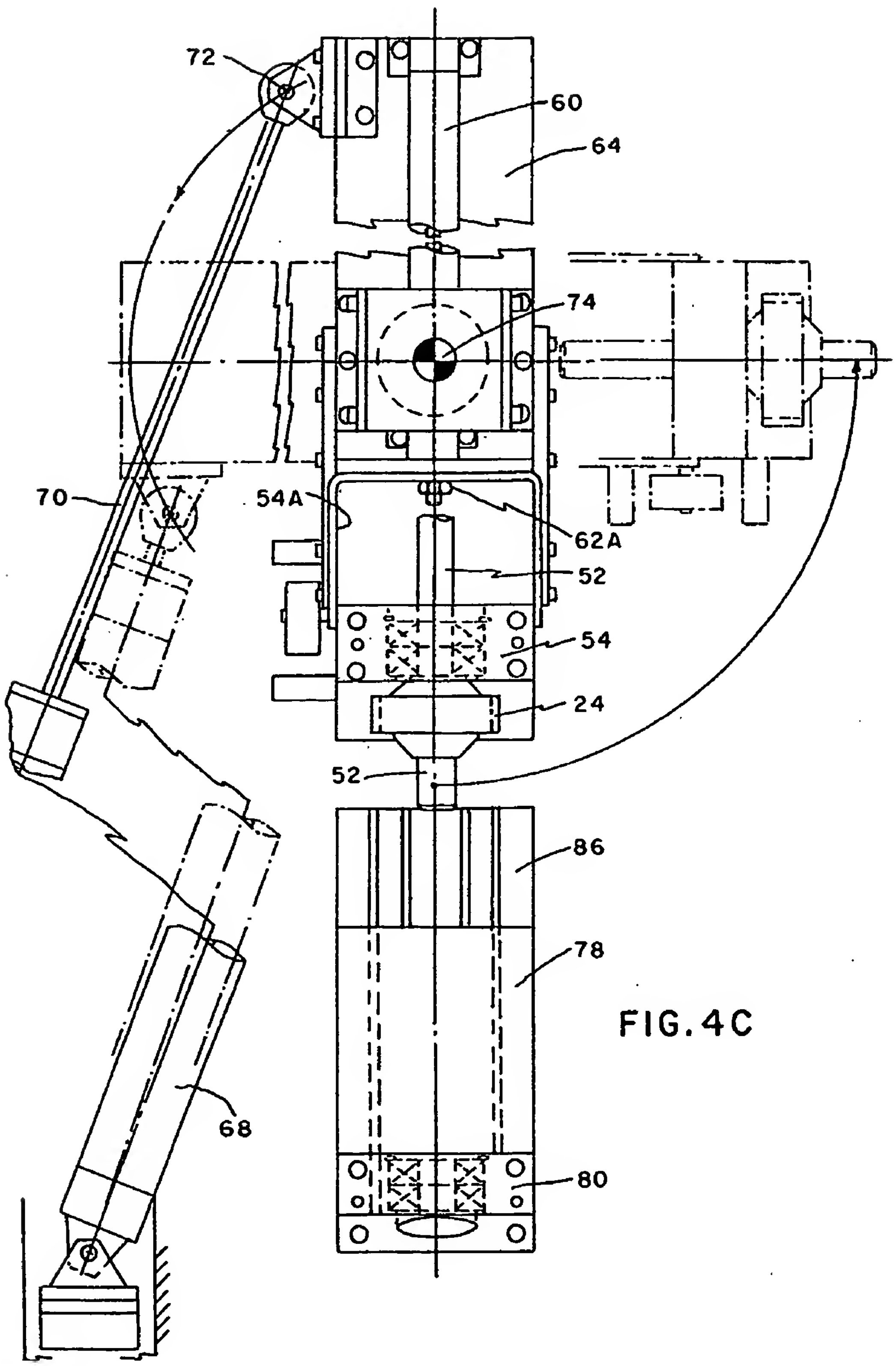



FIG. 4C

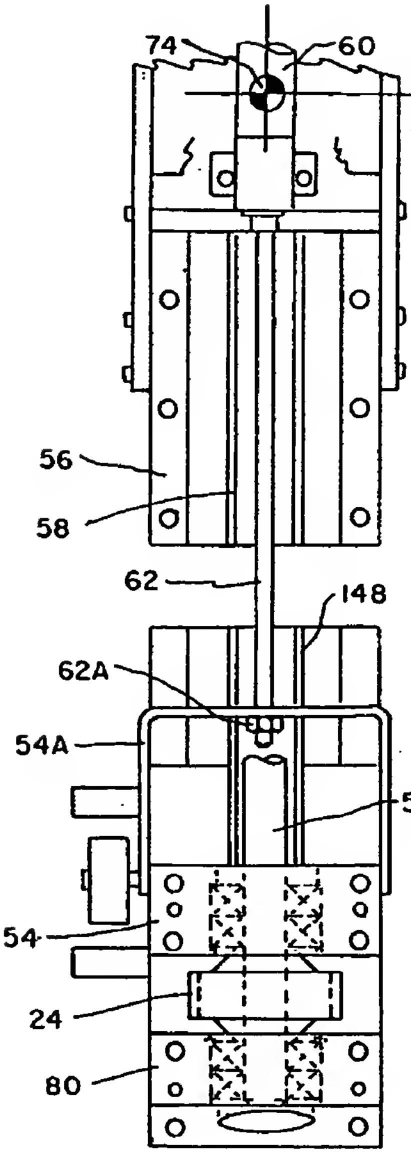



FIG. 4D

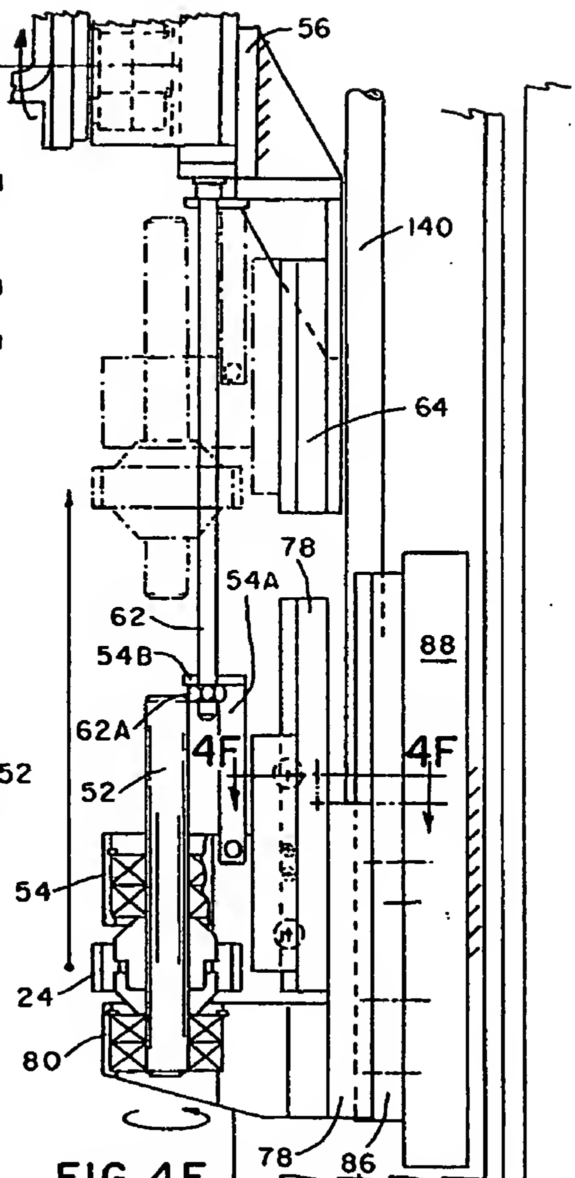



FIG. 4E

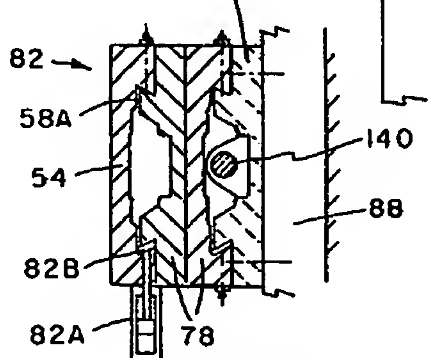



FIG. 4F

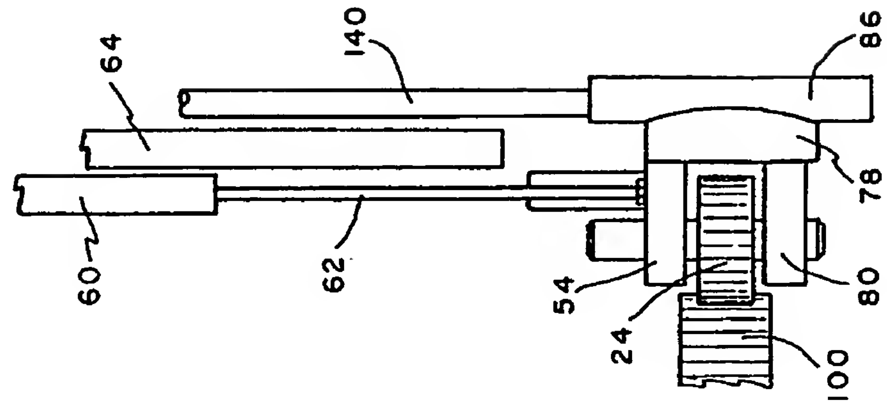



FIG. 4J

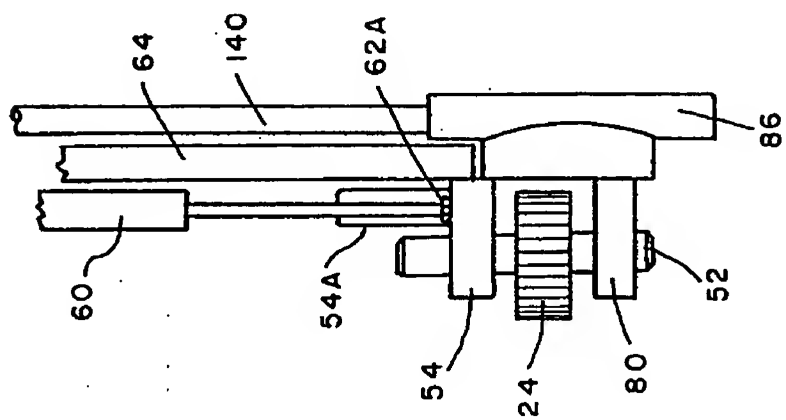



FIG. 4I

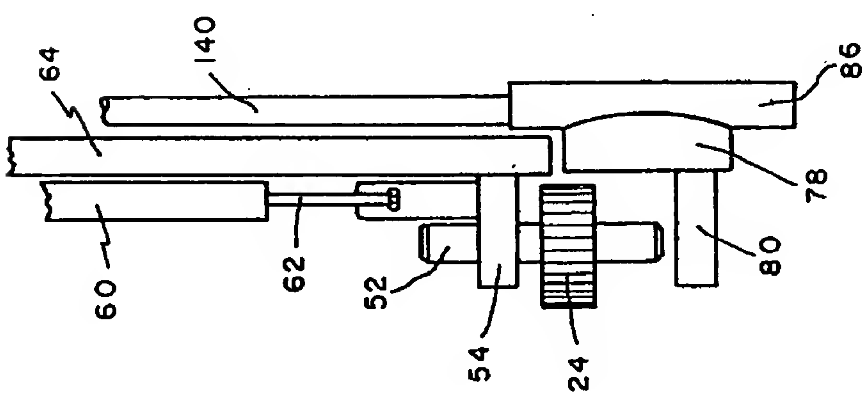



FIG. 4H

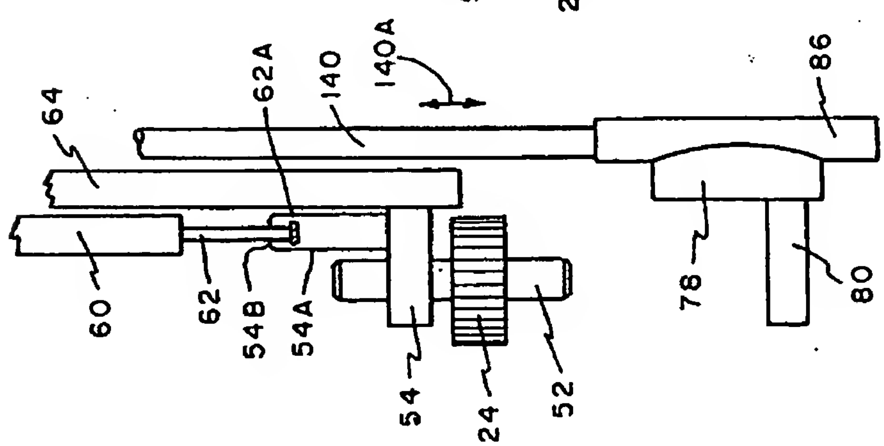



FIG. 4G

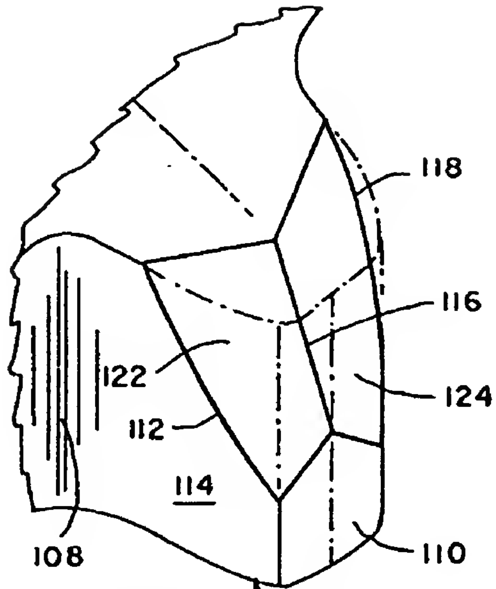



FIG.5

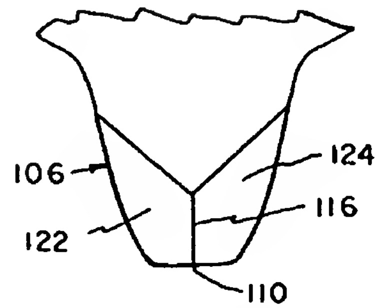



FIG.5A

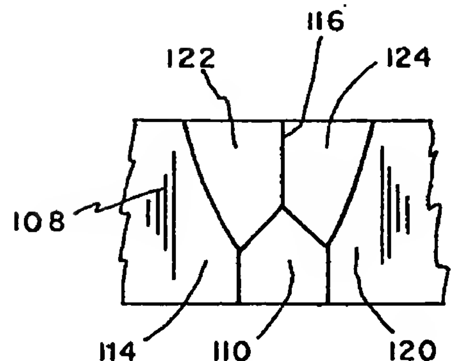



FIG.5B

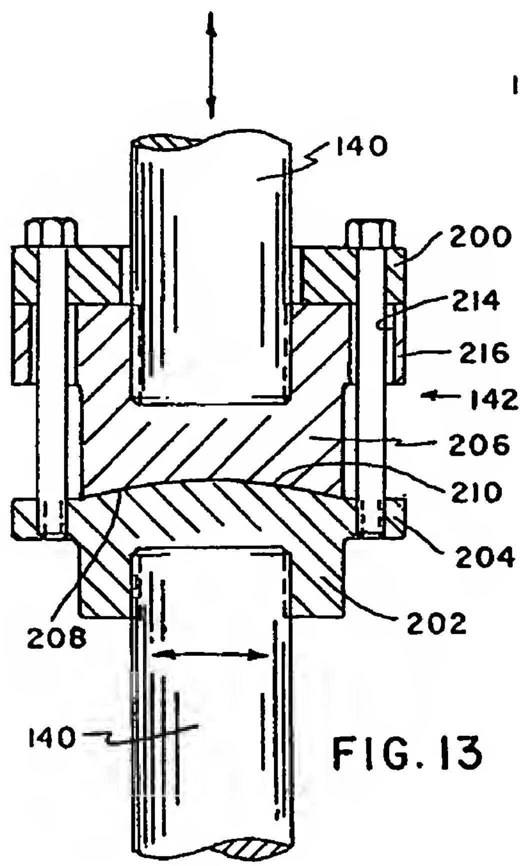



FIG. 13

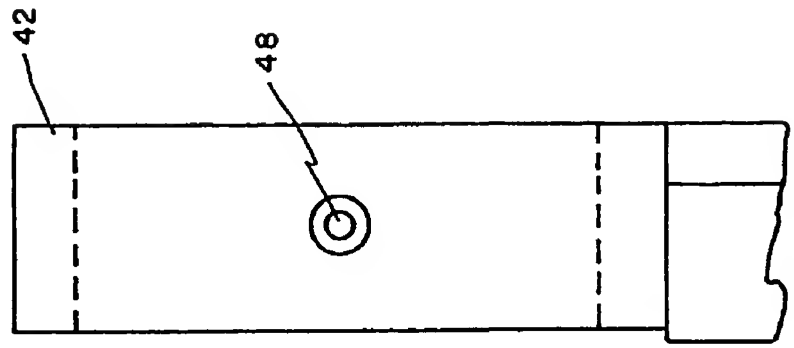



FIG. 7

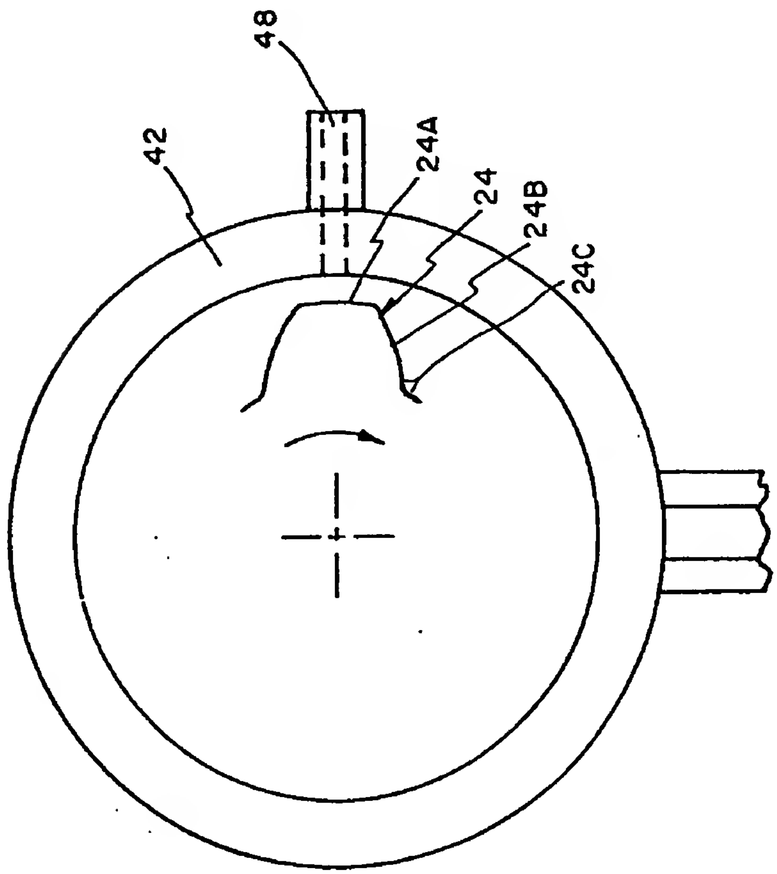



FIG. 6

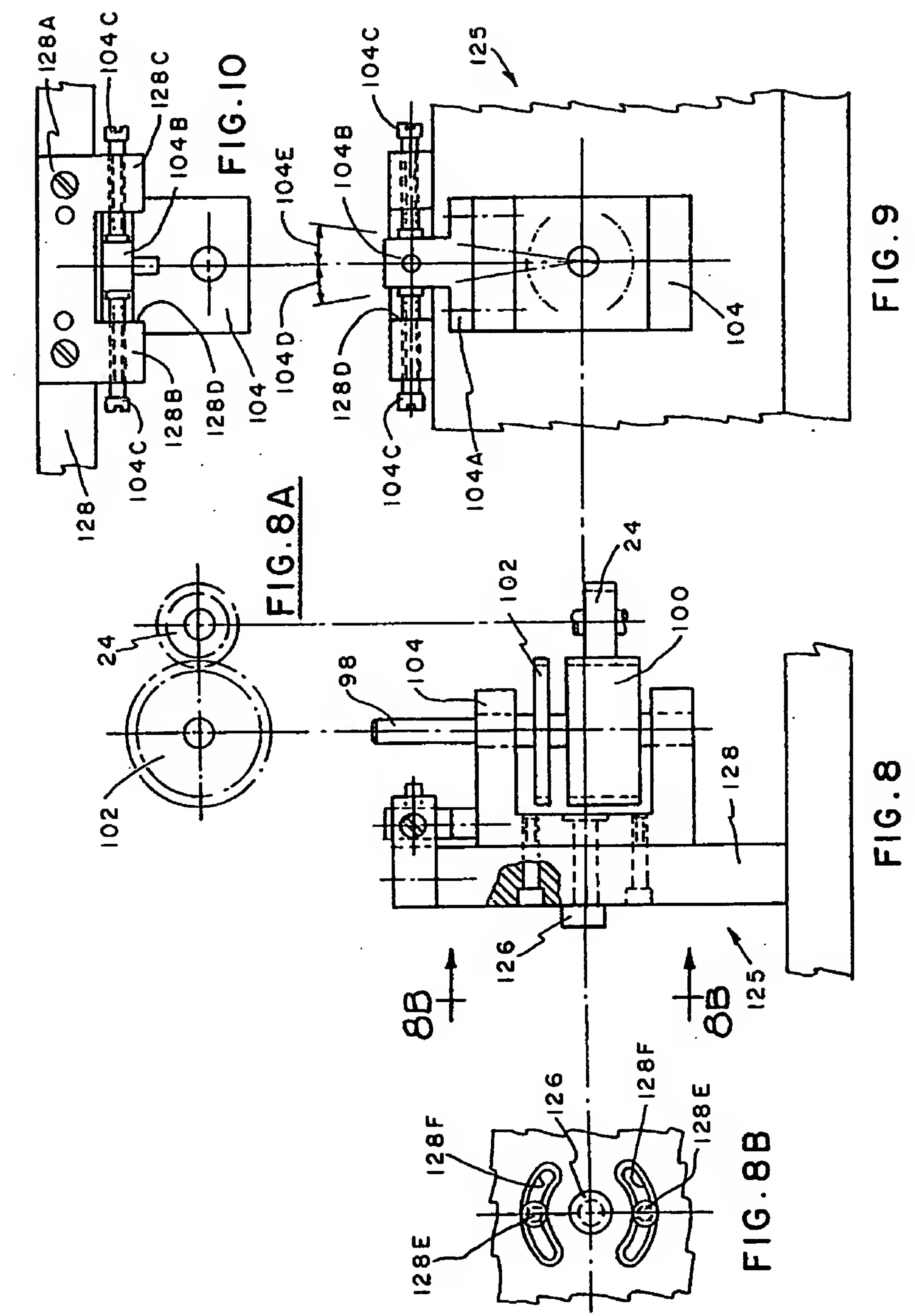


FIG.10
FIG.9
FIG.8A
FIG.8
FIG.8B
128A
104C
128C
104B
104E
104D
128D
128B
104
128
125
104A
24
102
100
98
126
8B
128F
128E

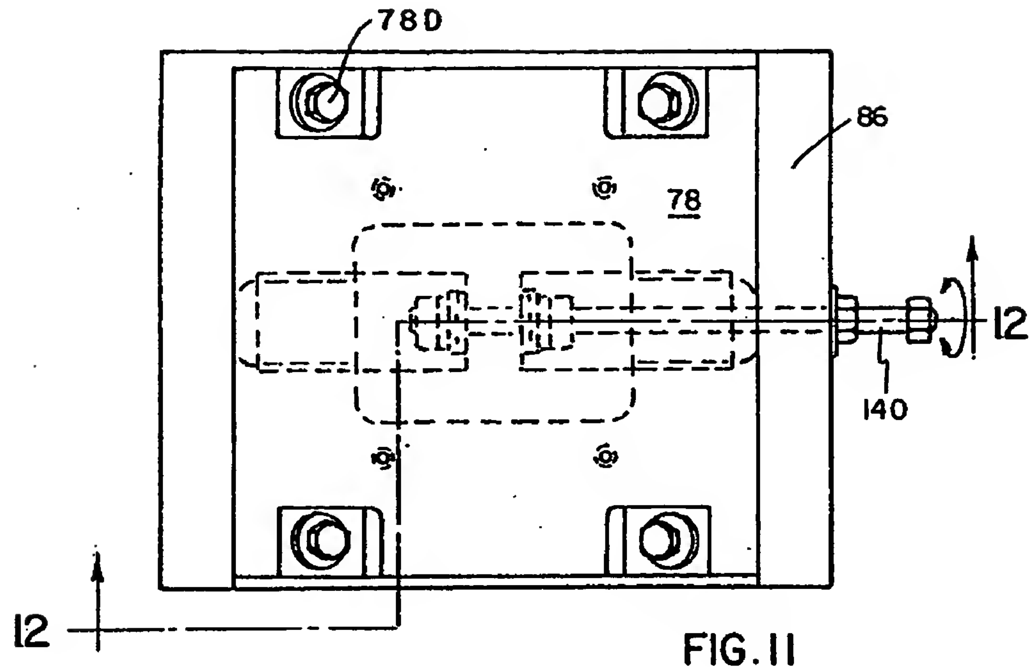



FIG. 11

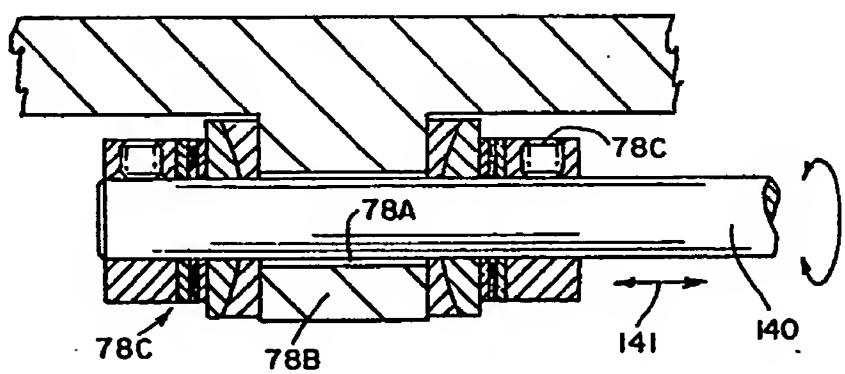



FIG. 12A

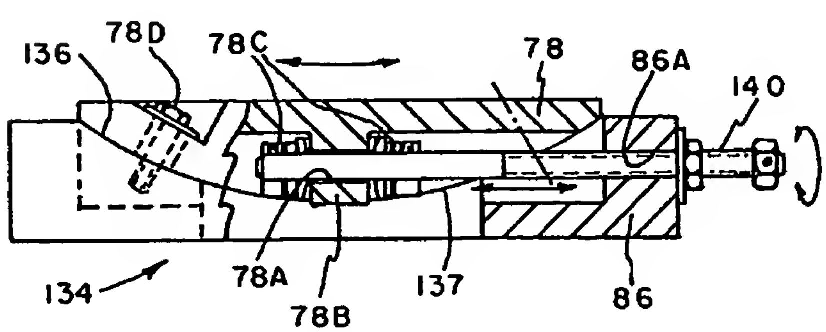



FIG. 12

# INDUCTION HEATING SYSTEM FOR A NEAR NET SHAPED GEAR BLANK

## GOVERNMENT SPONSORSHIP

This invention was made with Government support under Contract N00039-88-C-0051 awarded by the U.S. Department of the Navy. The Government has certain rights in the invention.

This is a divisional of application Ser. No. 07/829,187, filed on Jan. 31, 1992, U.S. Pat. No. 5,221,513.

## BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an apparatus for metallurgically treating steel gears by thermomechanical means to produce high strength and accurate contact surfaces through a net shape finishing process.

2. Description of the Prior Art

Highly loaded precision gears are normally manufactured by carburizing the surface of low carbon steel gears and reaustenitizing the entire gear prior to hardening by rapid quenching to below the temperature at which the diffusionless transformation process that creates the hardened martensitic structure proceeds to completion, the so-called $M_f$ temperature. For medium to high carbon steel gears only the surface of the gears are reaustenitized prior to quenching to produce the hardened martensitic structure. The hardened gears are then finished to net shape by grinding, skiving or other hard finishing operations. A method has been proposed in U.S. Pat. No. 4,373,973 in which a carburized gear is reaustenitized and quenched to above the start of the martensite transformation temperature, the so-called $M_s$ temperature, rolled and then quenched to martensite before any diffusional decomposition can form from he metastable austenite. This invention includes light cold-working or burnishing to complete the transformation of remaining austenite. However, no specific process details are described that produce the required metallurgical state for through-hardened, medium- or high-carbon steel gears. Nor does that disclosure describe a specific apparatus which can accomplish this process.

In reducing the concept of U.S. Pat. No. 4,373,973 to practice, we have discovered that certain critical basic issues must be addressed for a metallurgically sound and dimensionally accurate gear to be produced. To achieve metallurgically sound structures, the surface decarburization and attending oxide network characteristic of gas carburizing must be significantly reduced or eliminated. This is because, unlike conventional gear finishing, the outermost surface layers are not removed during the final finishing operation. Metallurgically sound gears also have retained austenite levels of less than 10 percent. Retained austenite is particularly prevalent with high carbon or high hardenability steel compositions. Highly accurate gear teeth require very precise control of the deformation process to minimize root slivers, lead direction errors, and profile direction errors. The present invention includes apparatus and methods to control both metallurgical quality and dimensional accuracy during thermomechanical gear finishing to produce the quality required of precision gears.

Gear finishing by rolling uses two types of motion: (1) in-feed motion in which the axes of the workpiece and the die are brought together to a fixed position to engage the mesh of each to accomplish the deformation process and (2) through-feed motion in which the axes are translated parallel to each other after meshing or synchronization at a fixed distance of separation. In conventional cold rolling operations either one or other method is used. In-feed motion is used primarily for helical gears in which there is no way to compensate for tooth-to-tooth dimensional variations. Through-feed motion is required for spur gears but conventional gear finishing machines do not compensate for dimensional variations along the lead direction. In order to successfully accomplish thermomechanical finishing by rolling, both processes must be used simultaneously and very accurate coordination between the two motions must be maintained to compensate for tooth-to-tooth and lead variations. As a prerequisite for precise control of the rolling die and workpiece during processing, the initial fixed setting must also be precisely controlled. For instance, axial out-of-plane misalignment between the workpiece and tool can produce lead errors. In-plane misalignment between workpiece and tool can lead to profile errors, a non-uniform profile contour along the lead direction, as well as lead errors.

Therefore, to produce gears by thermomechanical processing which possess desirable metallurgical properties and dimensional accuracy, it is necessary to maintain precise control over the environment, thermal conditions and mechanical actions.

## SUMMARY OF THE INVENTION

In accordance with the present invention there is provided an apparatus that performs thermomechanical processing of gears in which precise control of the thermal conditions, the environment and mechanical actions during the forming process is maintained.

The essence of this invention are the process control methods and architecture for accomplishing the precision motions, the thermal control, and the environmental control using a unique combination of sensors, mechanisms, and software.

The control architecture for the mechanical movements comprises absolute position control and load control of the through-feed motion and absolute position, high resolution relative position and load control of the in-feed motion. Appropriate transducers and sensors are used to monitor each of these motions and loads and the signals from them are used as feedback signals for generating the error signal used in the servo controlled actuators for in-feed and through-feed motion. An optical pyrometer based on infrared detection is used to monitor the temperature of the gear as it is being heated by an AF induction field. During this heating the workpiece is rotated at 100 RPM to distribute the heat uniformly around the circumference of the gear. IR radiation from the gear passes through a fiber optic link to an IR detector, generating a signal which is processed by a rapid response signal processor so that the instantaneous temperature on each tooth and on each portion of the tooth such as top, flank and root can be monitored. This temperature signal is passed continuously to a high speed digital/analog interface for transmission to a supervising microprocessor. The peak, mean and minimum values of tooth-to-tooth temperatures are then used in the control logic for controlling the process. The thermal history during induction heating is also recorded for off-line analysis.

When the thermal criteria have been met, the microprocessor then transmits the command signals to deen-

ergize the induction coil and to proceed with the next step of the process. The material handling mechanism then rapidly transfers the workpiece to a thermally controlled liquid working medium for quenching to the deformation temperature. After the workpiece has reached the deformation temperature, it is worked to its final dimension by combined in-feed and through-feed motion. Precise control of the operation is accomplished by the use of a pressure sensor in the line supplying hydraulic flow to a rotary hydraulic motor powering the rolling die. Variation in the pressure of the rotary hydraulic motor is detected when tight mesh between the workpiece and the die occurs. A signal generated from this detection is used as a logic value to establish the starting position for control of the deformation process. The in-feed motion is controlled from a signal from a high resolution displacement transducer which can measure displacements as fine as 0.0001 inch. The processing parameters are specified using a command generating software and are eventually downloaded to a supervising computer. A sequence generator allows the operator to program the operation with a series of two character commands but has built in checks to prevent operation that can inflict damage on either the workpiece or any part of the apparatus.

The region above the working medium fluid in which the gear is induction heated and subsequently manipulated prior to quenching is maintained in a nitrogen or argon environment. This feature minimizes unwanted oxidation and decarburization that can occur during this portion of the process.

Other and further features, advantages, and benefits of the invention will become apparent in the course of the following description taken in conjunction with the following drawings. It is to be understood that the foregoing general description and the following detailed description are exemplary and explanatory but are not to be restrictive of the invention. The accompanying drawings which are incorporated in and constitute a part of this invention, illustrate one of the embodiments of the invention, and, together with the description, serve to explain the principles of the invention in general terms. Like numerals refer to like parts throughout the disclosure.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an overall schematic diagram of the essential control architecture required to achieve successful thermomechanical processing in accordance with the invention;

FIG. 2 is a Time-Temperature-Transformation (T-T-T) Diagram of a typical and preferred alloy, 3Ni-1Cr steel, used for gear fabrication according to the invention;

FIG. 3 is a diagrammatic side elevation view of apparatus for gear processing as embodied by the invention;

FIG. 4 is a diagrammatic end elevation view of the apparatus illustrated in FIG. 2;

FIGS. 4A and 4B are detail diagrammatic views illustrating, respectively, two successive positions of components generally illustrated in FIG. 4;

FIGS. 4C and 4D are detail end elevation views of certain parts illustrated in FIG. 4;

FIG. 4E is a detail side elevation view of parts illustrated in FIG. 4C;

FIG. 4F is a cross section view taken generally along line 4D—4D;

FIGS. 4G, 4H, 4I and 4J are detail diagrammatic side elevation views illustrating successive positions of parts illustrated in FIG. 4D;

FIG. 5 is a detail perspective view of an individual tooth of an indexing gear utilized for purposes of the invention;

FIG. 5A is a detail side elevation view of the gear tooth illustrated in FIG. 5;

FIG. 5B is a detail top plan view of the gear tooth illustrated in FIG. 5;

FIGS. 6 and 7 are detail front elevation and side elevation views, respectively, of an induction coil heater used for purposes of the invention;

FIG. 8 is a side elevation view of an out-of-plane adjustment mechanism used for purposes of the invention;

FIG. 8A is a detail top plan view merely illustrating the outline of two components illustrated in FIG. 8;

FIG. 8B is a detail elevation view taken along lines 8B—8B in FIG. 8;

FIG. 9 is a front elevation view of the mechanism illustrated in FIG. 8;

FIG. 10 is a top plan view of the mechanism illustrated in FIGS. 8 and 9;

FIG. 11 is a detail top plan view of an in-plane adjustment mechanism utilized for purposes of the invention;

FIG. 12 is a cross section view taken generally along line 12—12 in FIG. 11;

FIG. 12A is a detail enlarged view of certain parts illustrated in FIG. 12; and

FIG. 13 is a detail elevation view, in section, of a component illustrated in FIG. 3,

## DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 illustrates diagrammatically and schematically a preferred system 20 for performing thermomechanical processing of gears in accordance with the present invention.

The invention can be considered as having two subsystems: a gear processing subsystem 22 by means of which the thermomechanical processes including heating and deformation are applied to perform the net shape processing of a workpiece 24 and a control subsystem 26 which provides for logic sequence and timing that are critical for the successful operation of the invention. As seen diagrammatically in FIGS. 3 and 4, the thermomechanical subsystem 22 is contained in an enclosed compartment 28 providing an inert gas environment for the heating and final quenching of the workpiece 24. A vessel 30 in a sealed relationship with the compartment 28 contains a liquid working medium 32 which may be a commercially available marquenching oil. The workpiece is rapidly immersed in the liquid medium 32 thereby quenching it to the thermomechanical processing temperature of the metastable austenite in which net shape forming is performed. This stage of the process is referred to, metallurgically, asausforming.

The workpiece 24 is referred to initially as a "near net shaped gear blank" and when all processes of the invention have been completed, it is referred to as a "net shaped gear". As a near net shaped gear blank, it may have been hobbed or otherwise formed using conventional techniques. As such, for purposes of the invention, the workpiece 24 is formed with its gear teeth approximately 0.001 to 0.002 inches oversized in tooth thickness relative to the final or desired size so that the gear can meet the dimensional tolerances of AGMA

required for high performance gears without the necessity of grinding. The displacement of the metal during the deforming operations performed in accordance with the invention serves to remove the excess tooth thickness while assuring the proper profile. Grinding is eliminated, and for this reason alone there can be as much as a 70% increase in surface durability at any given contact stress level.

High strength gears are generally fabricated from a low carbon alloy carburizing grade steel in which the surface and sub-surface regions have been enriched with carbon to a specified depth. The higher carbon content serves to increase the hardness and to strengthen the material along the gear contacting teeth surfaces and beneath the surface. The elevation in hardness results from transformation of the steel from the face centered cubic crystal structure known as austenite to the body centered tetragonal crystal structure of very fine grain size known as martensite. Less hard but tougher properties can be obtained by isothermal transformation to bainite or a mixture of bainite and martensite upon quenching.

In a conventional gear processing method, the workpiece is quenched rapidly through the austenitic region by immersion into quenching media below the $M_s$ temperature. The workpiece is subsequently tempered at a designated temperature to soften the structure and impart ductility. After the tempering treatment is complete, gear finishing is accomplished by grinding in a well known manner for high performance gears.

As mentioned above, the present invention eliminates the grinding operation to provide a microstructurally improved gear tooth surface as will now be described. An important part of this invention is to select a carburizing grade steel, such as carburized nickel-chromium steel, which has a transformation curve with a metastable austenitic condition just above the martensitic range for a period of time sufficiently long to allow shaping of the gear teeth surfaces. There is in shown FIG. 2, the time-temperature-transformation chart for nickel-chromium steel carburized to about 1.0% surface carbon. The carburized nickel-chromium steel is commonly used for manufacturing high performance gears in the aerospace industry.

The time-temperature-transformation curves show the times required for austenite to start and to complete transformation at each temperature. Temperature is indicated along the ordinate and time on a logarithmic scale is indicated along the abscissa.

After the carburized gear is heated above its critical temperature to an initial temperature 10, or approximately 1350° F., to render it austenitic, it is rapidly isothermally quenched (marquenched) from point 12 to point 14 at a rate exceeding a critical cooling rate in a liquid medium such as a standard marquenching oil which is maintained just above the temperature at which martensite starts to form and metastable austenite is obtained. A critical cooling rate is defined by the slope of line 12–14 that avoids the nose 16 of the transformation curve where austenite and cementite start to form.

To allow the maximum time for mechanically operating on the surfaces of the workpiece 24 while in the metastable austenitic condition, the cooling step must terminate temporarily at a temperature just above the martensitic condition. In FIG. 2, the point 14 beginning a new temperature plateau ending at point 17 is shown positioned at about 450° F.

Shaping of gear teeth further in accordance with this invention employs a process which is performed between points 14 and 17 whereby gear swaging or rolling or other operations are used to shape the gear teeth by deforming the metastable austenitic carburized layer prior to and before its conversion to martensite. This occurs during a pre-transformation time interval at a temperature below that for recrystallization of austenite and just above the $M_s$ of the carburized layer. This process, to be described, presents a means of developing ultra high strength in the current carburized case hardened gears processed by the conventional heat treat processing.

Following the shaping operation, the gear is transferred to a quench station, as indicated in FIG. 2 by line 17–18. Final quench, preferably utilizing a pressurized gas stream, although a liquid is within the scope of the invention, is initiated at point 18 and is finalized at point 19 in the martensitic range.

The control subsystem 26 of the invention comprises both hardware and software supervising and controlling the thermomechanical operations. The control subsystem is under the primary supervision of a microprocessor 34. All of the functions necessary for the operation of the mechanical, environmental and thermal functions of the apparatus are controlled from this computer. The software used for these functions are preinstalled prior to operation and the algorithms contained in the software are considered part of the invention. The machine operator has a choice of operating each function of the machine separately or initiating a sequence of operations that will actually perform the thermomechanical forming operation. The software is constructed in such a way that each separate function cannot proceed until a requisite condition exists in the apparatus. The sequence of operations or "program" is generated by the operator using a series of two character commands which are stored for execution. The algorithm checks for sequences of operation that cannot be permitted. The program commands are transferred to a unit 36 for routing to the proper component in system 26. The unit 36 is concurrently a high speed signal conditioner, an I/O interface, and a digital-/analog (D/A) converter.

During the operation of the system 20 (see FIG. 1), a control signal initializes all functions and sets up the individual subsystems and mechanisms for the operation to proceed. The process begins with a control signal from the interface 36 to an audio frequency (AF) control 38 which in turn energizes an AF work station 40 to provide an electric field to a toroidal-shaped, water cooled, induction coil heater 42 (see especially FIGS. 4, 6, and 7) into which the workpiece is temporarily positioned. The electrical field generated as the result of the operation of the induction coil may be 10 KHz, by way of example.

With particular reference to FIG. 2, which is a time-temperature-transformation diagram of a typical and preferred alloy used for gear fabrication, namely, 3Ni-1Cr steel, the workpiece 24 is heated to a temperature at which austenite is stable, whether it be a hypereutectic steel or a hypoeutectic steel. As heating proceeds, the temperature of the workpiece is monitored by means of an IR detector 44. An optical pyrometer which is an integral part of the IR detector performs this function, obtaining its information via a fiber optic link 46. Heat radiation from the workpiece is received through a sighting hole 48 in the coil 42 (see especially FIGS. 4, 6,

and 7) which is transmitted to a high speed thermal signal processor 50. A commercially available signal processor which has been found suitable for this purpose is Vanzetti Systems Infrared Thermomonitor Model No. 3008 manufactured and sold by Vanzetti Systems of Stoughten, Mass.

The signal processor 50 must have a sufficient response time to enable it to distinguish the variations in temperature from top 24A to flank 24B to root 24C of each tooth (see FIG. 6), typically, of a 4 inch diameter, 8 diametral pitch gear as it is rotated at speeds approximately in the range of 80 to 100 RPM, in a manner to be described, during the induction heating operation. The processed signal is then transmitted to the high speed digital to analog (D/A) converter 36 and in turn to the microprocessor based computer 34 in which the preprogrammed algorithm determines whether the temperature profile of the gear has achieved the requisite condition before proceeding to the next processing step. At that point, a logic signal is returned to the D/A converter 36 which sends the appropriate control signal to the induction coil control system represented by the controller 38 and work station 40 to turn off the energy field. The induction heating is performed within the enclosed compartment 28 in a controlled environment of nitrogen, or argon, or other suitable inert gas to minimize the amount of decarburization and oxidation of the workpiece surface.

The workpiece 24 is then rapidly transferred into the liquid working medium 32 where it is quenched to the metastable austenite condition. The mechanism for transferring the workpiece during the thermomechanical processing operation is best seen in FIG. 4 and its assoicated detail drawings, FIGS. 4A–4J. As with the induction heating operation, quenching of the workpiece 24 takes place in the controlled environment provided within the compartment 28.

A support spindle 52 on which the workpiece is suitably releasably secured is mounted for unitary rotation with an upper spindle bearing block 54 which is allowed to slide on the gear transfer slide plate 56 via dovetail slide ways 58 during the transfer operation. Induction heating takes place with the workpiece 24 in the horizontal or dashed line position (FIG. 4). For this operation, the workpiece 24 is extended on the support spindle 52 until it is positioned within the induction coil heater 42 (see especially FIG. 4A). Extension is accomplished by means of a workpiece transfer actuator 60 and its associated actuator rod 62 mounted on a transfer frame 64. After the workpiece is positioned within the induction coil heater 42, a friction drive wheel 66 engages the support spindle 52 to impart rotation to the workpiece during induction heating. A rotational speed in the range of 80 to 100 RPM has been found desirable for purposes of the invention.

When the induction heating cycle is completed, the workpiece is rapidly retracted from the induction coil. Retraction is accomplished by means of a lost motion mechanism which generally comprises a longitudinally extending bracket 54A, apertured transverse ear 54B, actuator rod 62, and an enlarged end 62A of the actuator rod. At one end, the bracket 54A is fixed to the bearing block 54 and the ear 54B is an integral part of its opposite end. The actuator rod extends slidably through the aperture ear 54B and terminates at the enlarged end 62A. In actual fact, the extreme end of the actuator rod 62 may be threaded and the enlarged end 62A may be a nut threadedly received on the apertured end to provide for adjustment of the lost motion mechanism. As seen in FIG. 4B, operation of the actuator 60 to retract the workpiece 24 from the heating zone of the induction coil heater 42 is effective to move the actuator rod 62 to the left (FIGS. 4A and 4B) until the enlarged end 62A engages the ear 54B, following which the bearing block 54 carrying the workpiece 24 and its spindle 52 is then slid to the left on the gear transfer plate 56.

The transfer frame 64 is then rotated to a vertical, or solid line, orientation (FIG. 4). This rotation is accomplished by a swivel actuator 68 operating through an actuator rod 70 whose extreme end is pivotally attached, as at 72, to the workpiece transfer frame 64 which is free to swing about a stationary axle 74. When the transfer frame 64 reaches the vertical orientation, the gear transfer actuator 60 is then operated to extend the workpiece 24 below the level 76 of the liquid working medium 32 within the vessel 30 where it is quenched to the metastable austenitic temperature. The transfer operation which includes withdrawal of the workpiece from the induction coil heater 42, swinging of the transfer frame 64 to the upright position, and immersion of the workpiece in the working medium 32 is performed in an extremely rapid manner, taking place over an interval of approximately two seconds.

The upper spindle bearing block 54 is then transferred via the transfer dovetail slide ways 58 (FIGS. 4 and 4D) to a gear support plate 78 so that the lower end of the workpiece support spindle 52 is captured within a lower spindle bearing block 80. This movement can best be seen with attention to FIGS. 4G–4J. A through-feed actuator 138, mounted on a top plate 139 (FIG. 3), imparts its motion to an actuator guide plate 86 by way of a through-feed rod connector 140. Selected operation of the actuator 138 serves to move the through-feed rod 140 in its longitudinal directions as indicated by a double arrow head 140A (FIG. 4G). After the workpiece transfer frame 64 has swung to the vertical position as indicated by solid lines in FIG. 4, the through-feed actuator 138 is operated to raise the through-feed rod 140, and with it the workpiece support plate 78 and the lower spindle bearing block 80 which is an integral part of the support plate 78. The actuator guide plate 86 is raised until the upper regions of the support plate 78 are proximate to the lower regions of the workpiece transfer frame 64. Thereupon, the actuator rod 62 operated by the workpiece transfer actuator 60 is advanced until its tip end engages the upper spindle bearing block 54. Continued operation of the actuator 60 is effective to transfer the bearing block 54 from the upper dovetail slideways 58 to lower dovetail slideways 58A provided on the workpiece support plate 78. The actuator 60 continues to extend the actuator rod 62 until the bearing block 54 has reached the position generally as indicated in FIG. 4J. The upper spindle bearing block 54 is then locked onto the gear support plate 78 by means of a dovetail locking mechanism 82 (see especially FIG. 4F) which includes hydraulically actuated gib locks.

As seen in FIG. 4F, the dovetail locking mechanism 82 comprises a hydraulic cylinder 82A which operates a gib 82B which, by its operation, eliminates the clearance between the sliding parts provided by the dovetail slideways 58A.

Through-feed motion, as represented by a double arrowhead 84 in FIG. 4, can then proceed by vertical translation of the actuator guide plate 86 on the in-feed translation plate 88. In-feed motion as represented by a double arrowhead 90 in FIG. 3 can proceed simulta-

neously by sliding of the in-feed translation plate 88 on in-feed slide guides 92 which are supported by in-feed slide bushings 94, all in a manner to be described below in greater detail.

At this point, the rotary actuator 96 which may be hydraulically operated can be activated to provide rotation, via an actuator shaft 98, to a coordinated rolling die 100 and indexing gear 102. Both the rolling die and the indexing gear are supported for rotation on an extension 98A of the actuator shaft 98 in a rolling die support frame 104. The axis of the workpiece 24 is positioned generally parallel to the plane of the axis of the rolling die 100 and of the indexing gear 102 so that meshing will occur as it passes through the indexing gear to synchronize or coordinate the rotation of the workpiece with that of the rolling die. In effect, the indexing gear 102 is a spur gear having modified teeth 106 (see FIGS. 5, 5A, and 5B). In FIG. 5, the outline of an original tooth is indicated by a combination of solid and dashed lines. As modified, indicated solely by solid lines, each tooth extends from a root 108 to a top land 110 and has been tapered on its lead side in a manner extending from a line 112 of departure from a flank 114 across a crest 116 to an opposite line of departure 118 from an opposite flank 120. This construction results in opposed tapered surfaces 122, 124 on the entry side of the teeth 106 which operate as cams to slightly rotate the workpiece 24 into synchronization with the rolling die 100. While other mechanisms could be used to move the workpiece into alignment with the rolling gear die 100 prior to their placement into a meshing relationship, the construction disclosed is a most economical one and is preferred.

The present invention provides for making appropriate adjustments should they be determined desirable to assure that an optimized gear will result from operation of the system 20. To this end, the mechanism of the gear processing subsystem 22 provides for both in-plane and out-of-plane adjustments which are provided relatively between the workpiece 24 and the rolling gear die 100.

The out-of-plane adjustment, that is, adjustment made outside of the plane defined by the axes of both the rolling gear die 100 and the workpiece 24, is provided by means of an adjustment mechanism 125 depicted in greater detail in FIGS. 8–10. By reason of this construction, the bifurcated rolling die support frame 104, when in the unlocked condition, is allowed to rotate around a pin 126. The pin 126 passes through the center of the die support frame 104 and through a load reaction frame 128 on which it is supported. Suitably mounted to an upper surface of the load reaction frame 128 is a cantilever plate 128A. The cantilever plate 128A has a pair of spaced finger members 128B, 128C which extend over the support frame 104 and define a recess 128D between them. An upper adjustment member 104A is also suitably attached to an upper surface of the support frame 104 and includes an them. An upper adjustment member 104A is also suitably attached to an upper surface of the support frame 104 and includes an integral head member 104B which extends upwardly into the recess 128D. Opposed adjustment screws 104C are threadedly received through the finger members 128B, 128C in opposed fashion to engage opposite sides of the head member 104B. Adjustment plate 128A is positioned above the level 76 (FIG. 4) of the liquid working medium 32. Out-of-plane adjustment as represented by angles 104D and 104E is accomplished by the appropriate operation of the adjustment screws 104C, screwing or unscrewing them in a unitary fashion to the extent desired. In order to secure the support frame 104 on the load reaction frame 128 when the desired out-of-plane adjustment has been achieved, a pair of locking bolts 128E which extend through arcuate grooves 128F and into threaded engagement with the support frame 104 are then tightened. This assures that the support frame 104 is locked against further additional undesired movement.

The in-plane adjustments, that is, adjustments made within the plane defined by the axes of both the rolling gear die 100 and the workpiece 24, are made on the workpiece support plate 78 with a locking mechanism 134 the control portions of which also extend above the level 76 (FIG. 4) of the liquid working medium 32. For purposes of the locking mechanism 134, the actuator guide plate 86 is provided with a hollowed-out region defined, in part, by an arcuate in-plane adjustment surface 136 which is congruent with a similar surface 137 on the workpiece support plate 78 opposite the surface on which the bearing blocks 54 and 80 are received. A terminal end of the through-feed rod 140 extends freely through a clearance hole 86A in the actuator guide plate 86, then through a clearance hole 78A in a projection integral with the support plate 78. Fasteners 78C of the ball joint variety serve to pivotably attach the free end of the connector rod 140 to the projection 78B. Longitudinal movement of the rod connector 140 as defined by double arrowhead 144 causes the gear support plate 78 to rotate normal to the radius of an in-plane adjustment surface 136, generally in the manner indicated by double arrowhead 141A. When the proper orientation of the workpiece support plate 78 relative to the actuator guide plate 86 has been achieved, a plurality of suitable fasteners 78D are then tightened to guard against the desired relative movement.

These mechanisms 130 and 134 permit the final adjustments of in-plane and out-of-plane alignments to be made when the system has reached thermal equilibrium. Once the adjustments have been made, the rolling die support frame 104 and the gear support plate 132 are locked in relative alignment. They remain so locked until it becomes desirable to make correcting adjustments at some future time.

As previously noted, through-feed motion is provided by a through-feed actuator 138, mounted on the top plate 139, which imparts its motion to the actuator guide plate 86 through the through-feed rod 140. To accommodate small incremental movements of the actuator guide plate 86 in the in-feed direction, a through-feed rod coupling 142 is provided to provide the through-feed rod 140 with a small amount of lateral flexibility. As seen particularly well in FIG. 13, the coupling 142 includes an upper ring member 200 which freely receives an end of the upper portion of the through-feed rod 140. A domed cap 202 with a peripheral flange 204 is fittingly received on an upper end of the lower through-feed rod 140 which matingly engages with an intermediate member 206 fittingly received on a lower end of the upper through-feed rod 140 and having a lower concave surface 208 slidably engaged with a concave surface 210 of the domed cap 202. The outer peripheries of the upper ring member 200 and of the domed cap 202 are joined by means of studs 212. The studs 212 pass freely through clearance holes 214 provided in an annular flange 216 of the intermediate member 206. It will be appreciated that as the actuator guide plate 86 moves in the direction of a dou-

ble arrowhead 90 (see FIG. 3), the surfaces 208, 210 will be caused to slide slightly relative to one another and thereby provide the requisite lateral movement of the through-feed rod 140 without causing damage to the system.

The in-feed motion is produced from an in-feed actuator 150 also mounted on the top plate 139 and is transmitted to a sliding in-feed wedge 152 through an in-feed rod connector 154. The vertical motion of the sliding in-feed wedge 152 transmits force to the vertically fixed in-feed wedge 155 which in turn provides in-feed motion to the in-feed translation plate 88. The taper of the wedge mechanism may be, for example, 40:1. The friction of the sliding in-feed wedge 152 is minimized by the use of linear roller bearings 156 between it and the load reaction frame 128 and the in-feed wedge 155. The in-feed translation plate 88 is guided in the horizontal position by four in-feed slide guides 92. Two return springs 160 on the bottom in-feed slide guides 92 and extending between the load reaction frame 128 and the in-feed translation plate 88 provide a return force when the in-feed actuator 150 is withdrawn. The entire working assembly is mounted on a bed plate 162 which is attached to the top plate 139 by four spaced support columns 164.

The workpiece 24 is advanced axially along its lead direction at a preprogrammed rate of through-feed velocity, programmed as incremental position feedback. During this operation the pressure resisting entry of the workpiece is monitored by a through-feed load cell 166 connected between the through-feed actuator 138 and the workpiece 24 by the through-feed rod connector 140. If the through-feed resistance exceeds a preset limit further advance is prevented. Simultaneously the required in-feed position is provided by the in-feed actuator 150 to the in-feed translation plate 88. The in-feed motion determines the position of the workpiece axis relative to the rolling die axis, which is measured by a high resolution displacement transducer 168 located above the level 76 of the liquid working medium 32. The signal from this transducer is the primary feedback for maintaining the proper degree of engagement between die and workpiece. A high resolution displacement transducer 168 measures distance between the axes of the workpiece 24 and the rolling gear die.

In order to properly control the forming action, the amount of absolute displacement between the surfaces of the die teeth and the workpiece teeth must be controlled. This is accomplished by determining the point of meshing contact between the die and workpiece by detecting the increase in hydraulic pressure from a pressure sensor 170 in the rotary actuator 96. This signal is then returned to the microprocessor 34 via the I/O interface 36 where it is used to initialize the signal from the high resolution displacement transducer 168. The in-feed pressure is also monitored with an in-feed load cell 172 to determine if unexpected high in-feed loads are produced by the forming action. The microprocessor 34 will generate a signal to delay in-feed motion if the loads are beyond the pre-set limit. Alternatively, forming loads can be used as the primary control signal and the high resolution displacement transducer 168 can be used to monitor axial displacement. Both in-feed and through-feed processing signals including load, position and displacement are continually monitored and recorded on the hard drive of the computer for later analysis.

After the thermomechanical deformation is complete, the workpiece 24 is removed from the liquid working medium 32 and quenched with a stream of gas from a gas quench system 174. For this operation, the entire sequence previously described following heating of the workpiece and its subsequent immersion into the liquid working medium is re-traced.

The control system employs servovalve operated actuators in which the feedback signals from the through-feed loop is directed to a through-feed conditioner 176 and after conditioning directed to a through-feed servocontroller 178 where it is compared with the command signal to generate the error signal for the servovalve. Likewise the in-feed actuator 150 receives an error signal through the loop containing an in-feed signal conditioner 180 and an in-feed servocontroller 182. Command signals from the command signal generator 36 are alternately provided to each loop to effect operation simultaneously.

While preferred embodiments of the invention have been disclosed in detail, it should be understood by those skilled in the art that various other modifications may be made to the illustrated embodiments without departing from the scope of the invention as described in the specification and defined in the appended claims.

We claim:

1. Apparatus for heating a workpiece in the form of a near net shaped gear blank having carburized gear teeth surfaces above its critical temperature to obtain an austenitic structure throughout its carburized case, said apparatus comprising:
- a toroidal shaped induction heater defining a heating zone;
- upper support means for rotatably mounting the workpiece proximate to and aligned with the heating zone;
- workpiece actuator means for selectively moving the workpiece between a retracted position displaced from said heating zone and an advanced position within the heating zone;
- drive means for rotating the workpiece in the heating zone; and
- temperature sensing means distant from said toroidal heater and directed at the workpiece for detecting the temperature in rapid sequence of a plurality of locations on the gear teeth surfaces of the workpiece as the workpiece rotates in the heating zone.

2. Apparatus as set forth in claim 1 wherein said upper support means includes:
- an elongated workpiece transfer frame;
- a bearing block movable on said transfer frame between first and second positions; and
- a workpiece support spindle rotatably mounted on said bearing block.

3. Apparatus as set forth in claim 2
- wherein said induction heater has a central axis;
- wherein said support spindle is rotatable on a spindle axis which is coaxial with the central axis; and
- wherein said actuator means includes:
  - a workpiece transfer actuator; and
  - an actuator rod operably associated with said transfer actuator having a free end engageable with said bearing block movable between a first and a second position for advancing the workpiece, respectively, from the retracted position to the advanced position.

4. Apparatus as set forth in claims 3 wherein said actuator means includes lost motion means for moving

the workpiece from the advanced position to the retracted position.

5. Apparatus as set forth in claim 4 wherein said lost motion means includes:

a guide member fixed on said bearing block including: an elongated base member fixed at one end to said bearing block and extending in a direction of said transfer actuator; and

a traverse ear on said base member distant from said bearing block having a through hole to slidably receive said actuator rod; and

wherein said actuator rod includes a stop member on an extremity thereof engageable with said traverse ear for moving the workpiece from the advanced position to the retracted position upon movement of said actuator rod from the second position to the first position.

6. Apparatus as set forth in claim 1 wherein said drive means includes a rotatable drive wheel selectively movable between a non-driving position disengaged from said support spindle and a driving position tangentially engaged with said support spindle for rotating the workpiece within the heating zone.

7. Apparatus as set forth in claim 1

wherein said induction heater has an outer peripheral surface and an inner peripheral surface and a radially directed sighting hole extending from said inner peripheral surface to said outer peripheral surface; and

wherein said temperature sensing means includes infrared detection means positioned to be generally coplanar with said induction heater and with the workpiece when in the advanced position and aligned with the sighting hole for detecting the temperature of the gear teeth surfaces of the workpiece.

8. Apparatus as set forth in claim 1 including:

Computer means for energizing said induction heater to impart heat to the heating zone; and

signal processor means coupled to said temperature sensing means for recording a plurality of temperatures of the workpiece as it rotates within the heating zone;

said computer means responsive to operation of said signal processor means for calculating an average temperature of the workpiece from the plurality of temperatures sensed and recorded and for deenergizing said induction heater when the average temperatures calculated reach predetermined values.

9. Apparatus as set forth in claim 1 including:

signal processor means coupled to said temperature sensing means for recording for each tooth of the workpiece temperatures at one or more locations including the top, root, and flank thereof; and

computer means responsive to operation of said signal processor means for calculating average temperatures of the one or more locations of the teeth of the workpiece from the temperatures sensed and recorded and for deenergizing said induction heater when the average temperatures calculated reach predetermined values.

10. Apparatus as set forth in claim 1 wherein said computer means includes means for pulsing the energy to said induction heater to thereby impart heat intermittently to the heating zone.

11. Apparatus as set forth in claim 1 wherein said induction heater is an AF induction heater whose electric field operates in the range of approximately 10 KHz.

12. Apparatus as set forth in claim 1 including an enclosure providing an inert atmosphere for all operations performed on the workpiece.

13. Apparatus as set forth in claim 1 including:

computer means for selectively energizing said induction heater to impart heat to the heating zone; and

signal processor means responsive to operation of said temperature sensing means for continuously calculating and recording the temperature of the top and of the root of each tooth of the workpiece;

said computer means being responsive to operation of said signal processor means for continuously averaging the temperatures of the tops of the teeth of the workpiece and for continuously averaging the temperatures of the roots of the teeth of the workpiece and for comparing the average temperatures of the tops of the teeth of the workpiece with a predetermined temperature and for comparing the average temperatures of the roots of the teeth of the workpiece with a predetermined temperature, said computer means being operable for deenergizing said induction heater when the average temperatures measured are within a predetermined range of the predetermined temperature in each instance.

14. Apparatus as set forth in claim 1 including:

signal processor means responsive to operation of said temperature sensing means for continuously calculating and recording the average peak temperature of all the teeth of the workpiece; and

computer means responsive to operation of said signal processor means for continuously comparing the average peak temperature of all the teeth with a predetermined temperature and for deenergizing said induction heater when the average peak temperature detected is within a predetermined range of the predetermined temperature.

15. Apparatus as set forth in claim 1 including:

signal processor means responsive to operation of said temperature sensing means for continuously calculating and recording the temperatures of all of the teeth of the workpiece;

said computer means being responsive to operation of said signal processor means for continuously comparing the minimum temperature of all of the teeth with a predetermined temperature and for deenergizing said induction heater when the minimum temperature detected is within a predetermined range of the predetermined temperature.

* * * * *

US-PAT-NO: 5770838

DOCUMENT-IDENTIFIER: US 5770838 A

TITLE: Induction heaters to improve transitions in continuous heating system, and method

---------- KWIC ---------

Drawing Description Text - DRTX (4):
FIG. 3 is a schematic representation of the connection between the heating system and a programmable control means.

Detailed Description Text - DETX (5):
Now referring to FIG. 3, in the preferred embodiment of the invention a programmable control mechanism 300 directs the heating of the preceding heating section 52 and the following heating section 56 and the use of the induction heating section 54. In other embodiments of the invention, the control mechanism may not be programmable. The programmable control mechanism 300 directs the heating via a programmable control system 302 that is interconnected with the preceding heating section 52, the induction heating section 54, and the following heating section 56 through conduit 304 to direct the operations of the heating system 50. In other embodiments of the invention, a wireless transmission system (not shown) may be used in place of

or in conjunction with conduit 304. Instrumentation in the heating system 50 measures at least a portion of the variables (discussed below) of the combined strip 40 and of the heating system 50 and generates variable signals 310. Conduit 304 sends the variable signals 310 from the heating sections to the programmable control system 302. Additional variables that are not measured by the instrumentation are determined by a heating system operator and are manually inputted into the programmable control system 302 via an input device 306.

Detailed Description Text - DETX (6):

There are numerous variables that are received by the programmable controller 302. Some of the variables for the first strip are length 24, width 28, and thickness 29. Some of the variables for the second strip are length 26, width 30, and thickness 31. Other important variables in heating the first and second strips 10 and 16 include the initial temperature of the strips, the strips' speed through the heating system 50, and the exit temperature of the strips. Instrumentation may be used to measure a portion of these variables, i.e., thermocouples, distance indicators, speed indicators, etc.

Detailed Description Text - DETX (8):

The programmable control system 302 analyzes the variable signals 310 and the manually inputted variables in the context of a thermal model 308 to

determine new operating parameters for heating system 50. The thermal model 308 is a mathematical model that simulates the heat transfer between the heating system 50 and the combined strip 40 and the results of changes in the operating conditions of the heating system to determine new operating parameters. After the analysis, the programmable control system 302 translates the new operating parameters into operating parameter signals 312 that are sent to the heating system 50 via the conduit 304 to direct the operations thereof. In other embodiments of the invention, the operating parameters are determined by a heating system operator who either manually, or via a control system, directs the operations of the heating system 50.

Detailed Description Text - DETX (15):

Prior to the first strip 10 entering the heating system 50, the programmable control mechanism 300 sends operating parameter signals 312 to the first and following heating sections 52 and 56 to heat the different zones in the sections to attain a first temperature profile. The first temperature profile is established by the temperatures of the combustion zones 101-112 at which the first strip 10 can exit the heating system 50 within a predetermined first temperature tolerance range. Likewise, a second temperature profile enables the second strip 16 to exit the heating system 50 within a second predetermined temperature tolerance range. The temperature profiles are established in the first and following heating sections 52 and 56 and

US005770838A

# United States Patent [19]

**Rohrbaugh et al.**

[11] **Patent Number: 5,770,838**

[45] **Date of Patent: Jun. 23, 1998**

[54] **INDUCTION HEATERS TO IMPROVE TRANSITIONS IN CONTINUOUS HEATING SYSTEM, AND METHOD**

[75] Inventors: **David S. Rohrbaugh**, Sellersville; **Steven R. Peterson**, Huntingdon Valley, both of Pa.

[73] Assignee: **Drever Company**, Huntingdon Valley, Pa.

[21] Appl. No.: **712,531**

[22] Filed: **Sep. 11, 1996**

[51] **Int. Cl.**$^6$ .............................. **H05B 6/06**; H05B 6/14

[52] **U.S. Cl.** ......................... **219/645**; 219/656; 219/662; 219/667; 146/568; 266/129

[58] **Field of Search** .................................. 219/645, 646, 219/635, 636, 656, 662, 665, 667; 146/567, 568, 576; 266/129

[56] **References Cited**

U.S. PATENT DOCUMENTS

| | | | |
|---|---|---|---|
| 1,981,631 | 11/1934 | Northrup | 219/667 |
| 2,123,776 | 7/1938 | Hansell | 219/656 |
| 2,504,440 | 4/1950 | Meiss | 219/645 |
| 2,902,572 | 9/1959 | Lackner et al. | 219/10.41 |
| 3,444,346 | 5/1969 | Russell et al. | 219/10.61 |
| 4,039,794 | 8/1977 | Kasper | 219/656 |
| 4,054,770 | 10/1977 | Jackson et al. | 219/10.61 |
| 4,093,839 | 6/1978 | Moliterno et al. | 219/656 |
| 4,239,483 | 12/1980 | Iida et al. | 432/8 |
| 4,420,667 | 12/1983 | Lewis | 219/656 |
| 4,585,916 | 4/1986 | Rich | 219/10.61 |
| 4,678,883 | 7/1987 | Saitoh et al. | 219/10.61 |
| 5,472,528 | 12/1995 | Boyer | 148/567 |
| 5,487,795 | 1/1996 | Kim et al. | 219/656 |

FOREIGN PATENT DOCUMENTS

2 688 802 9/1993 France .

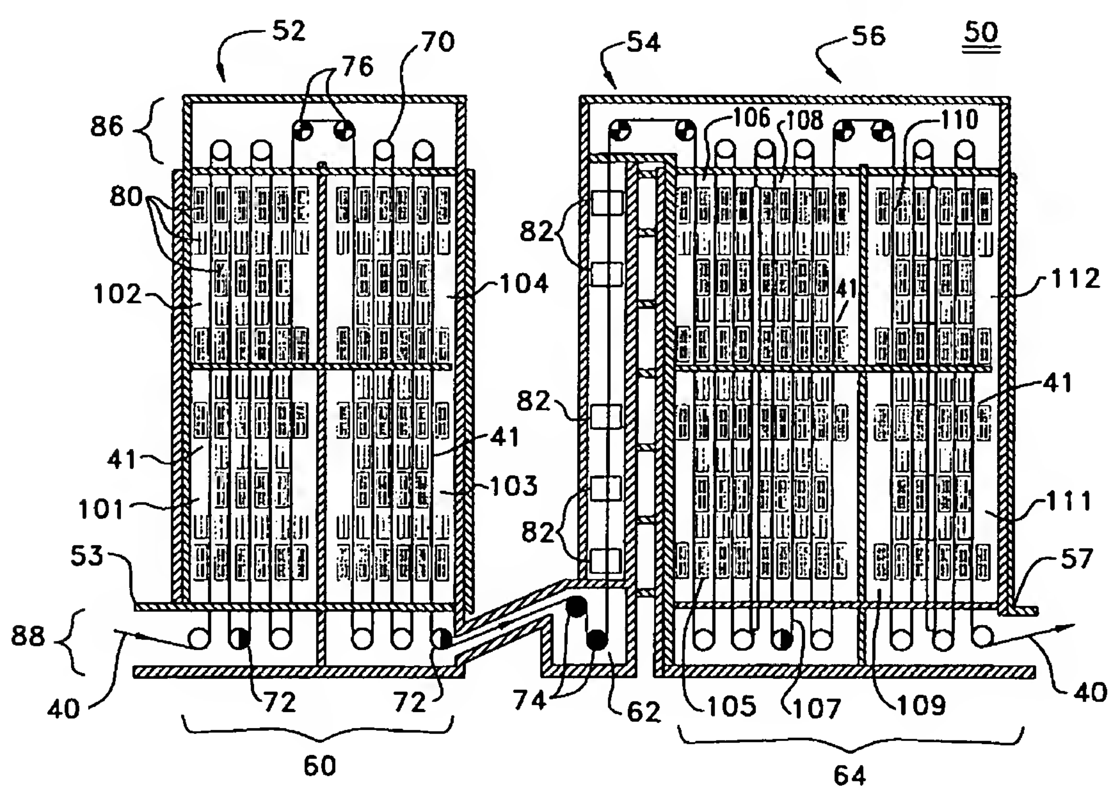
*Primary Examiner*—Philip H. Leung

*Attorney, Agent, or Firm*—Woodcock Washburn Kurtz Mackiewicz & Norris LLP

[57] **ABSTRACT**

A heating system and method for heating a metal strip to within a predetermined temperature tolerance range while the metal strip serially travels through a heating system. The heating system has at least one preceding heating section, at least one induction heating section, and at least one following heating sections, with the heating sections being serially arranged. The metal strip is heated to below the Curie point of the metal strip in the preceding heating section. Next, the metal strip is heated to, at a maximum, approximately the Curie point in the induction heating section. Then, the metal strip is heated to above the Curie point and to within the predetermined temperature tolerance range in the following heating section.

**26 Claims, 7 Drawing Sheets**



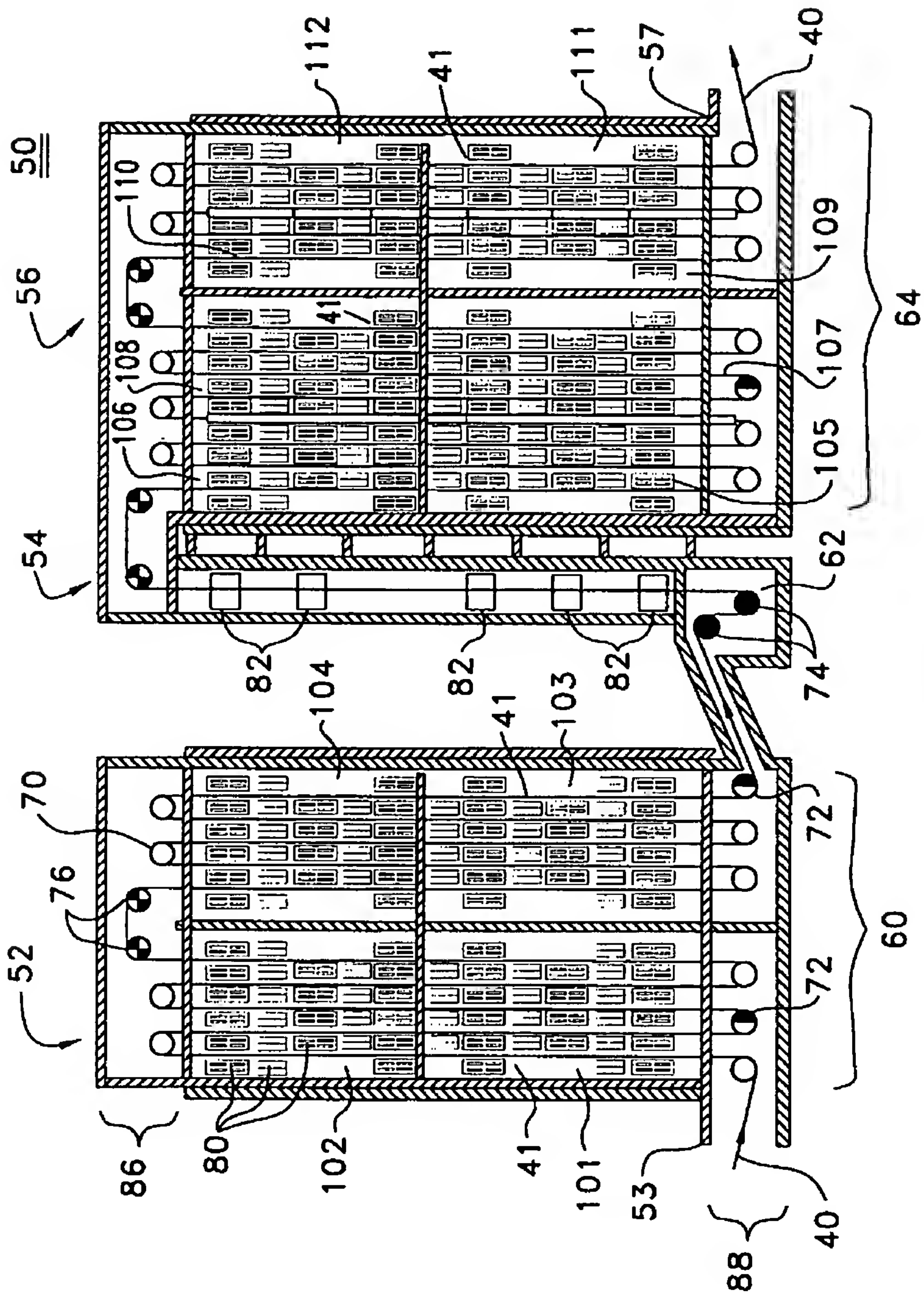

50
56
54
52
112
41
111
57
40
110
109
108
106
107
105
64
62
82
74
104
103
72
70
76
60
86
80
102
101
53
88

FIG. 1

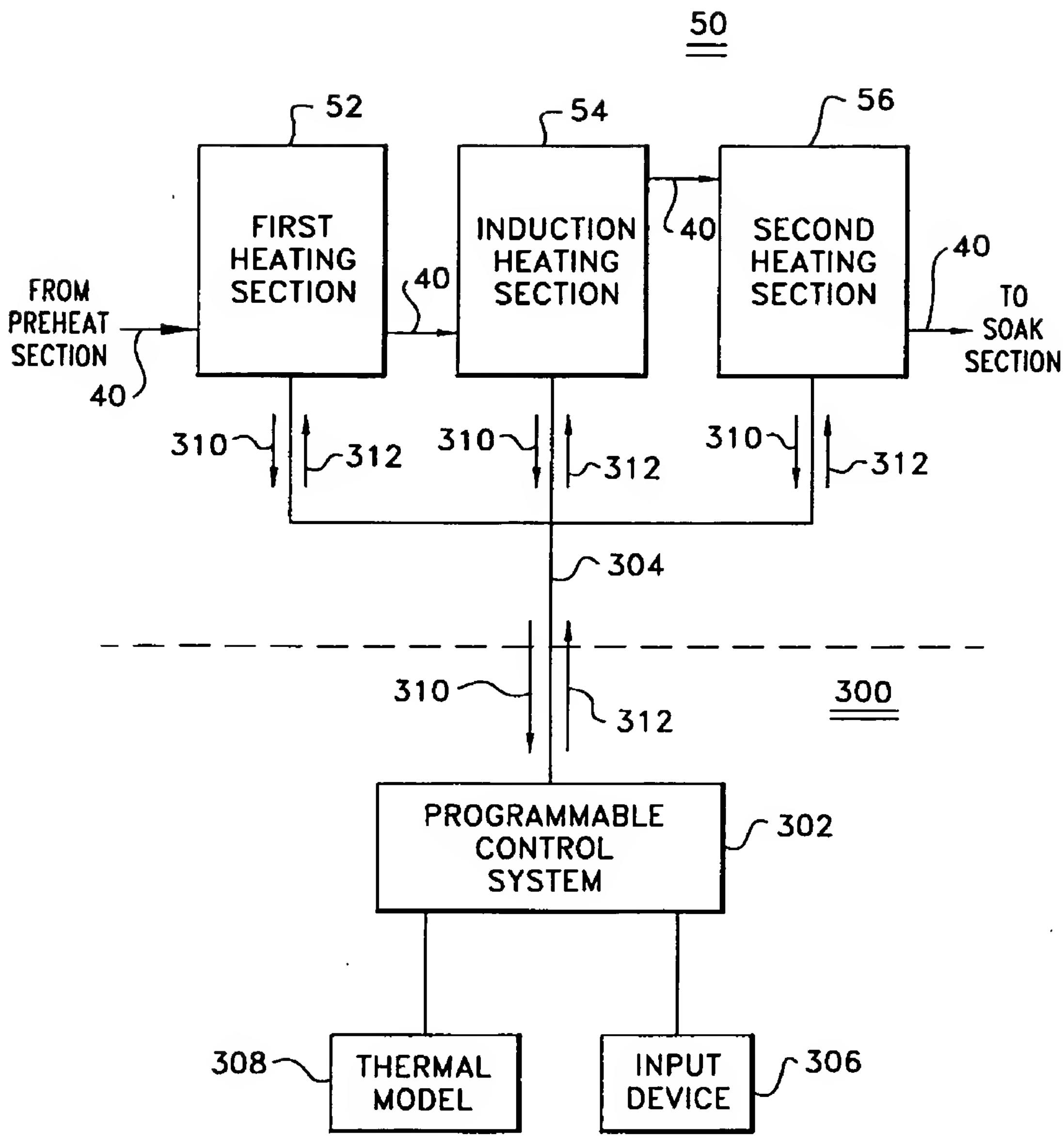

50
52
54
56
FIRST HEATING SECTION
INDUCTION HEATING SECTION
SECOND HEATING SECTION
FROM PREHEAT SECTION
40
40
40
40
TO SOAK SECTION
310
312
310
312
310
312
304
310
312
300
PROGRAMMABLE CONTROL SYSTEM
302
308
THERMAL MODEL
INPUT DEVICE
306

*FIG. 3*

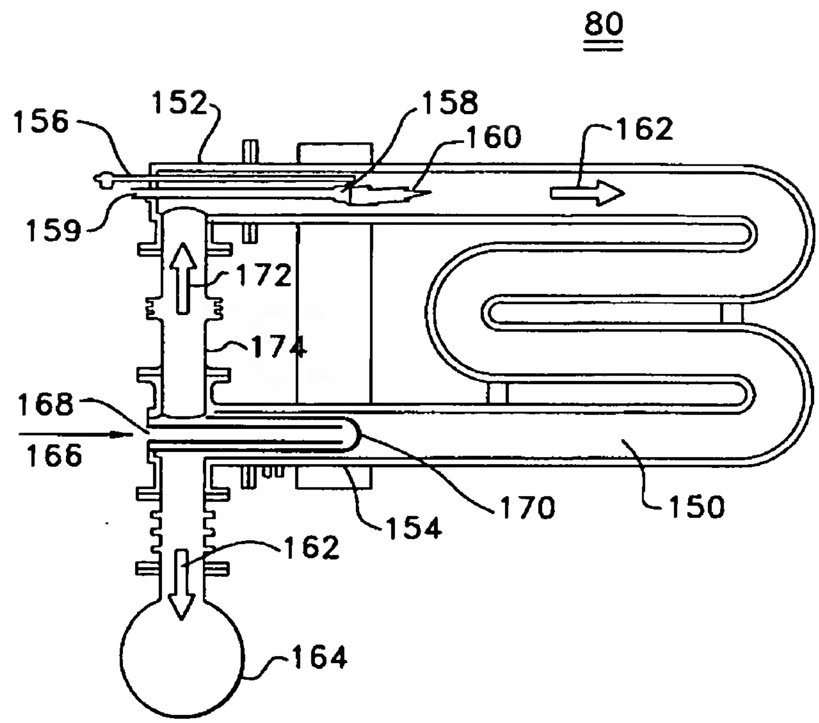

80
156
152
158
160
162
159
172
174
168
166
170
154
150
162
164

FIG. 4

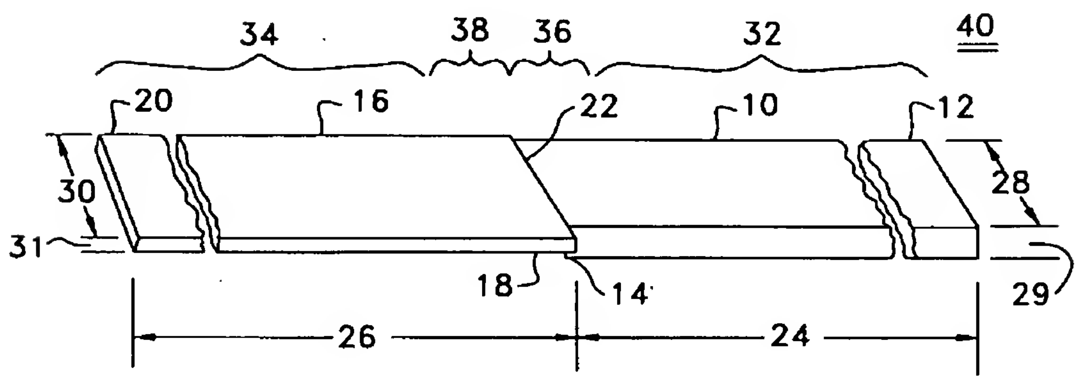

34
38
36
32
40
20
16
22
10
12
30
28
31
18
14
29
26
24

FIG. 2

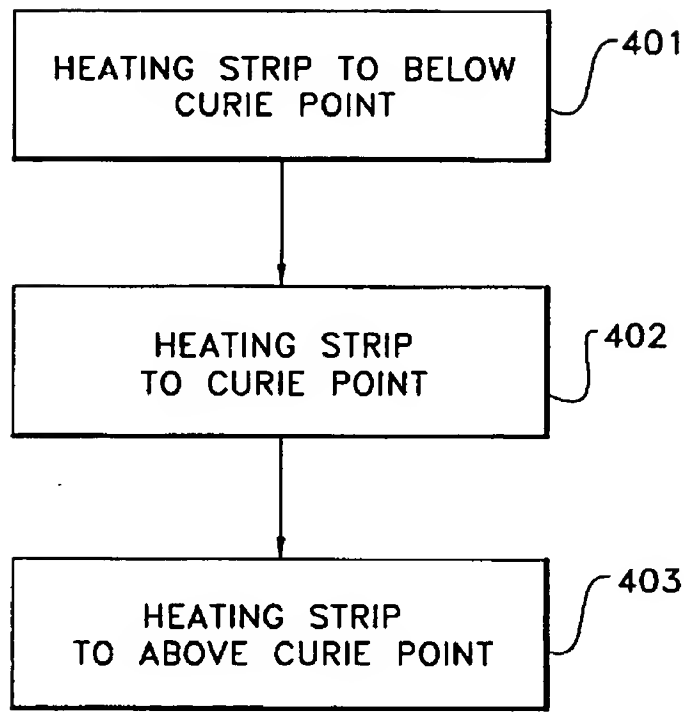

HEATING STRIP TO BELOW CURIE POINT
401
HEATING STRIP TO CURIE POINT
402
HEATING STRIP TO ABOVE CURIE POINT
403

*FIG. 5*

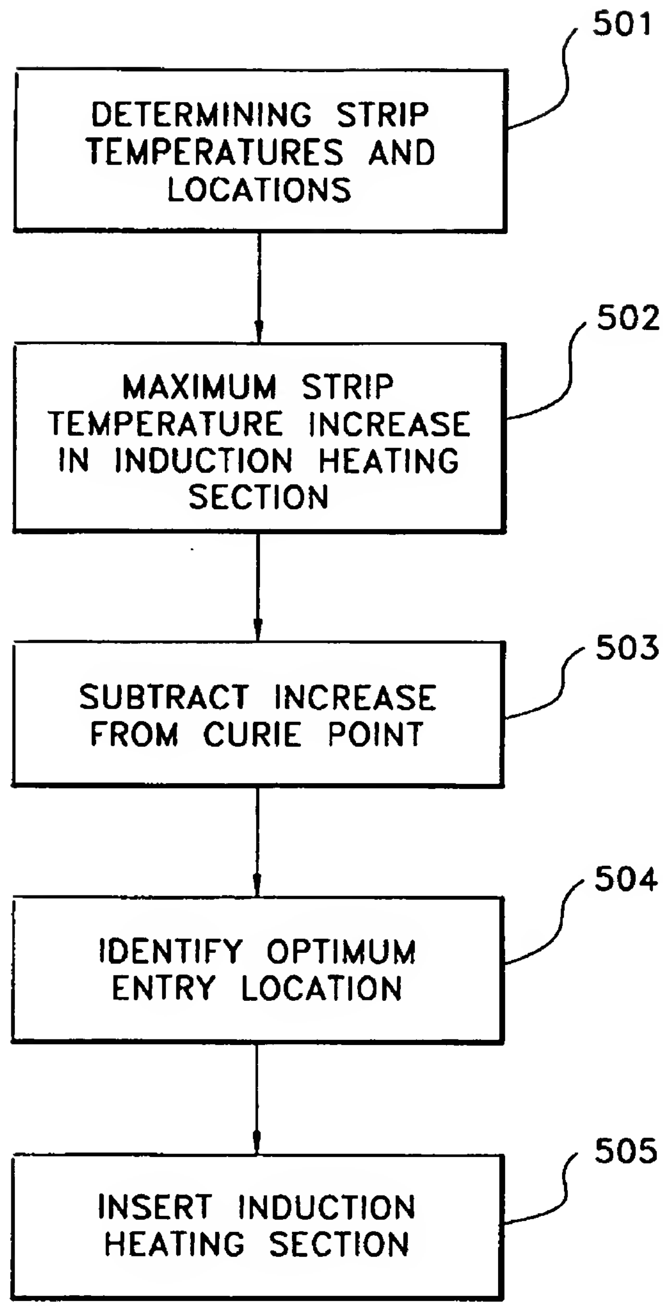

501
DETERMINING STRIP TEMPERATURES AND LOCATIONS
502
MAXIMUM STRIP TEMPERATURE INCREASE IN INDUCTION HEATING SECTION
503
SUBTRACT INCREASE FROM CURIE POINT
504
IDENTIFY OPTIMUM ENTRY LOCATION
505
INSERT INDUCTION HEATING SECTION

*FIG. 6*

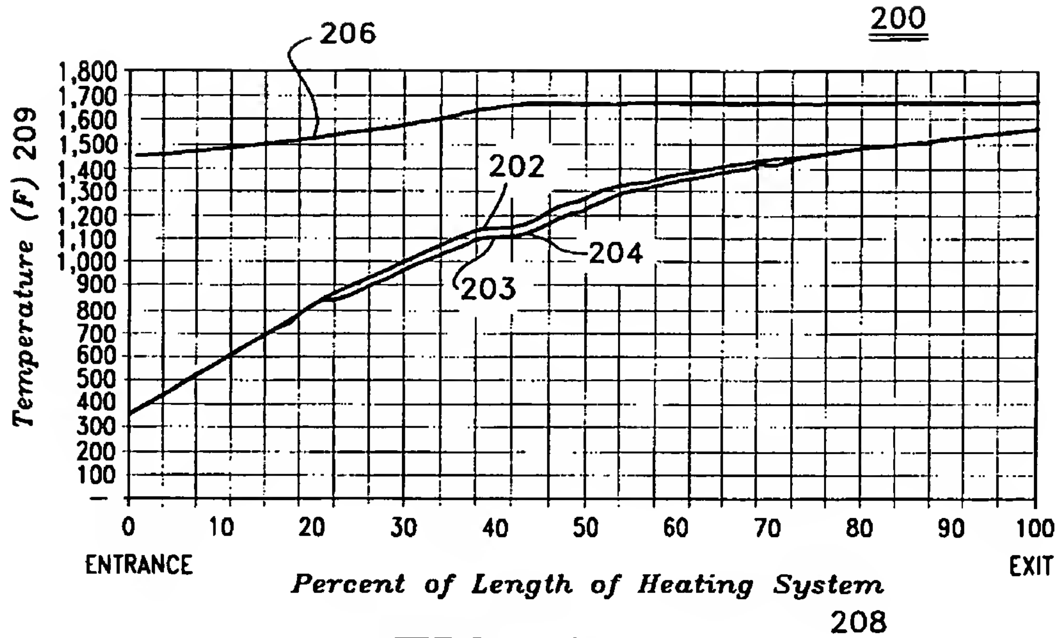

200
206
202
204
203
1,800
1,700
1,600
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
Temperature (F) 209
0
10
20
30
40
50
60
70
80
90
100
ENTRANCE
EXIT
Percent of Length of Heating System
208

*FIG. 7*

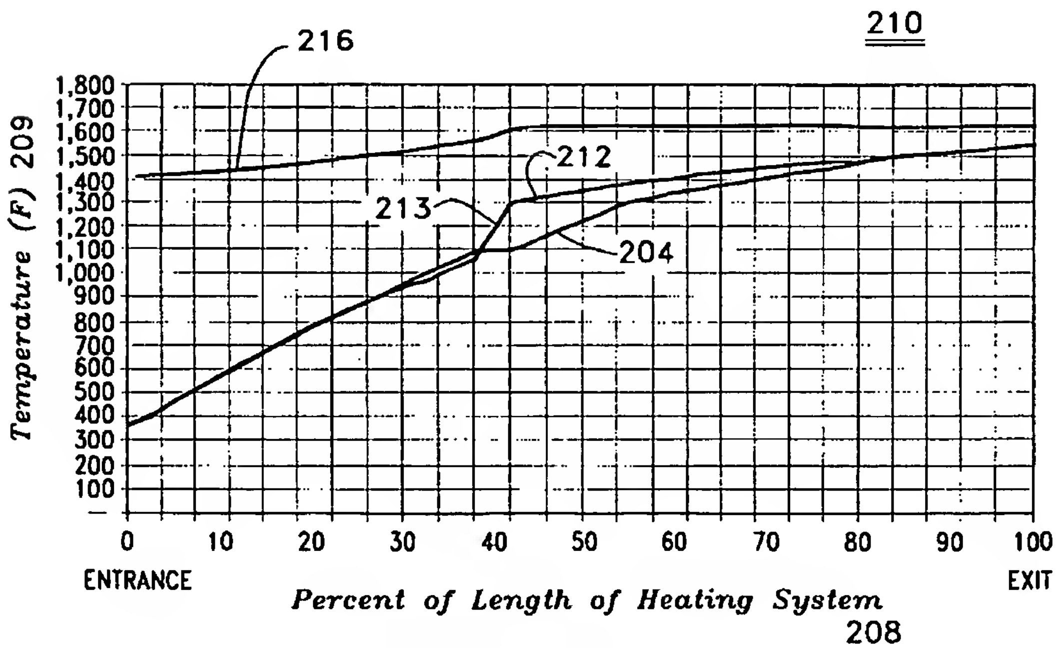

210
216
212
213
204
1,800
1,700
1,600
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
Temperature (F) 209
0
10
20
30
40
50
60
70
80
90
100
ENTRANCE
EXIT
Percent of Length of Heating System
208

*FIG. 8*

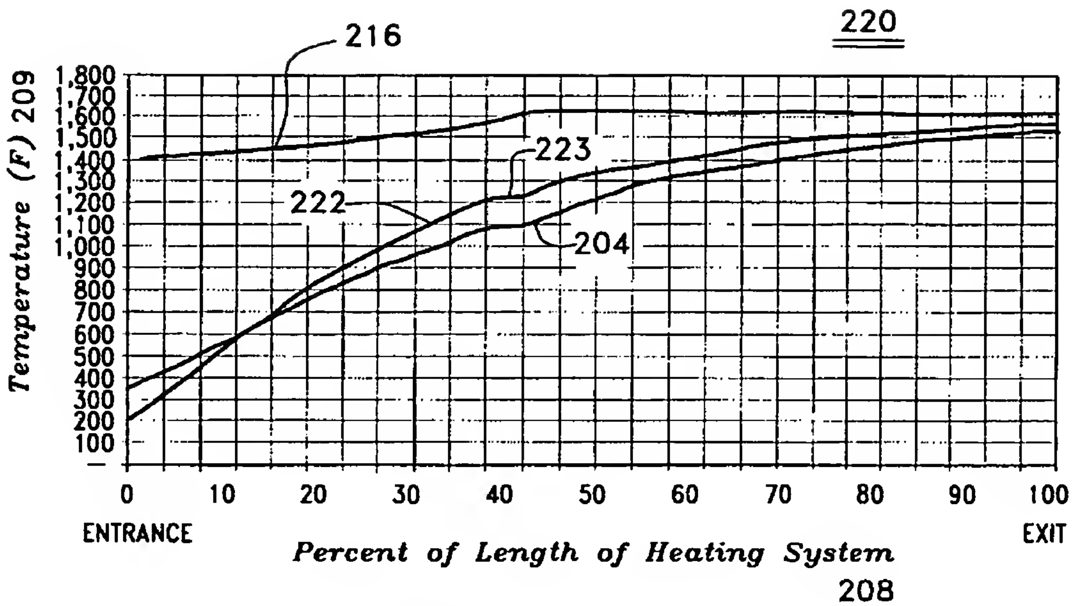

220
216
223
222
204
1,800
1,700
1,600
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
Temperature (F) 209
0 10 20 30 40 50 60 70 80 90 100
ENTRANCE
EXIT
Percent of Length of Heating System
208

*FIG. 9*

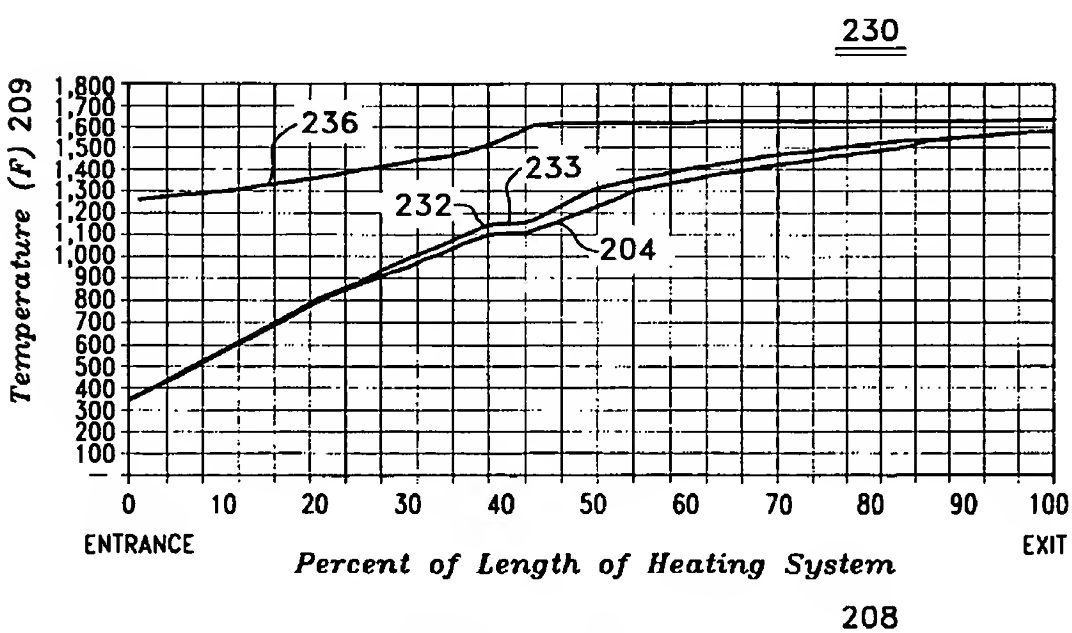

230
236
233
232
204
1,800
1,700
1,600
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
Temperature (F) 209
0 10 20 30 40 50 60 70 80 90 100
ENTRANCE
EXIT
Percent of Length of Heating System
208

*FIG. 10*

# INDUCTION HEATERS TO IMPROVE TRANSITIONS IN CONTINUOUS HEATING SYSTEM, AND METHOD

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

This invention relates to the heating of metal strips passing through a continuous heating system. More specifically, this invention relates to the heating of metal strips to within predetermined temperature tolerance ranges.

### 2. Description of the Prior Art

Generally, continuous heating furnaces are used for continuously annealing or galvanizing steel strip, band, or plate, which shall be referred to collectively as "strip." Specific heating procedures are established to impart desired characteristics to the strip. Each heating procedure has a predetermined peak metal temperature tolerance range to which the strip should be heated within upon leaving the furnace, irrespective of the dimensions of the strip.

Such furnaces can be broadly classified into those that are heated electrically and those that are heated by burning gas. The gas-fired furnaces can be subclassified into the radiant-tube type and the direct-fired type. Considering energy efficiency, running cost, initial investment and other factors, the gas-fired furnaces may be much more advantageous than the electrically-heated furnaces.

When continuously heat-treating strips of different dimensions, it is a common practice to serially pass the strips through the furnace. Often, but not always, the strips are welded together before continuously feeding them through the furnace. The region between the strips is referred to as a transition. Transitions can be categorized as to changes in strip thickness, strip width, thermal cycle, strip speed, or any combination of the four previously mentioned parameters from one order, or coil, to the next. When transitions pass through the furnace system, special control techniques are required to change the furnace conditions due to the large thermal mass of the furnace system.

Prior art furnaces have been limited in the range of allowable transitions. If the transition is too large, the furnace will produce a large amount of strip which does not satisfy the tolerances (usually ±20° F.) on the desired peak metal temperature. This out of tolerance strip is generally scrap product because the physical properties of this strip will not be to specification.

The prior art discloses several techniques used to improve furnace performance for transitions. The simplest of these techniques is to use feedforward control to prepare the furnace for the incoming coil. This has typically been done with mathematical models which simulate the heat transfer between the furnace and the strip to predict optimal furnace conditions for the transitions. This method is helpful, but is still subject to the relatively sluggish response rate of a main fuel-fired or electrical resistance-heated furnace and the associated thermal mass.

Another prior art technique is to have a type of preheat system that can respond relatively rapidly, such as convection, direct-fired, transverse flux or induction. These units can then be used to add heat to one of the coils in the transition to produce a peak metal temperature that is not normally possible with the conditions that exist within the furnace at the time of the transition. All of these units have been installed at the entry to the main heating section and all have been used, in various forms, to improve the responsiveness of the process.



See U.S. Pat. No. 4,239,483 (Iida)(induction heaters). These units are generally used in conjunction with the previously mentioned modeling to broaden the range of transitions. However, the strip is still subject to the conditions of the furnace, resulting in the preheating section having a very limited impact on the peak metal temperature.

In theory, the ideal location for such a rapidly responding heating device would be where the strip exits the furnace so that the furnace does not limit the device's usefulness. However, this is not practical with the currently available technology. Most induction heaters are limited to raising the temperature of a strip to its Curie point, which is approximately 1300° F.–1400° F. As the typical peak metal temperature is higher than the Curie point, these induction heaters are not useful at the end of the furnace. The induction heaters that heat metal strip higher than the Curie point are not practical in continuous annealing due to very small coil openings and/or great losses in heating efficiencies. Transverse flux heaters can be used at these temperature ranges, but it is not practical from a physical viewpoint. Convection heating in this temperature range is also impractical from a mechanical and maintenance viewpoint. Direct-fired heaters cannot be used at the higher peak metal temperatures because of the tendency for oxidation of the strip surface.

Thus, a need exists for a way to reduce or eliminate out-of-specification metal strips that occur when transistions travel through the furnace.

## SUMMARY OF THE INVENTION

The present invention is directed toward a continuous strip heating system and method of operation thereof, the heating system having induction heaters positioned between a plurality heating sections of a continuous strip heating system, wherein the inclusion of the induction heaters allows for less strip scrap while the heating system has its temperature changed to accommodate changes in dimensions and other heating requirements of the strip.

Accordingly, it is an object of the invention to provide a heating system and method for heating a metal strip to within a predetermined temperature tolerance range while the metal strip serially travels through a heating system. The heating system has at least one preceding heating section, at least one induction heating section, and at least one following heating section, with the heating sections being serially arranged. The metal strip is heated to below the Curie point of the metal strip in the preceding heating section. Next, the metal strip is heated to, at a maximum, approximately the Curie point in the induction heating section. Then, the metal strip is heated to above the Curie point and to within the predetermined temperature tolerance range in the following heating section.

Other and further objects and advantages will appear hereinafter.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevation view of the heating system comprising an induction heating section between the preceding and following heating sections.

FIG. 2 is a perspective view of a combined strip comprising two strips of different dimensions.

FIG. 3 is a schematic representation of the connection between the heating system and a programmable control means.

FIG. 4 is a sectional view of a W-type tube heater used in the heating sections.

FIG. 5 is a flow chart of a method to heat a metal strip in a heating system comprising an induction heating section.

FIG. 6 is a flow chart of a method to optimally locate an induction heating section in a heating system.

FIGS. 7 through 10 are graphs of the temperatures of the heating system during the changing of the temperature of the heating system to accommodate a change in the strip's dimensions.

## DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

Referring to the drawings, wherein like numbers designate like components, FIG. 1 illustrates heating system **50**, or furnace, for heating a continuously moving combined strip **40** to within a peak metal temperature tolerance range or some other predetermined temperature tolerance range. Heating system **50** is located upstream of a soaking section and downstream of a preheating section in a continuous steel strip annealing line. Other invention embodiments are useful in processes requiring heat treatment of a metal strip, such as continuous strip galvanizing lines or in continuous plate furnaces. The heating system **50** has a top section **86** and a bottom section **88** extending across a preceding heating section **52**, an induction heating section **54**, and a following heating section **56** arranged in series. Other embodiments of the invention have a plurality of preceding and/or following heating sections. Further embodiments embodiments of the invention have the heating sections **52**–**56** arranged vertically. Still further embodiments have the heating sections in a plurality of housings or in a single housing. These arrangements enables combined strip **40** to enter the preceding heating section **52** at entrance **53**, pass through the three heating sections, and exit through following heating section exit **57**.

The combined strip **40** travels through the heating sections **52**, **54**, and **56** in passes **60**, **62**, and **64** respectively. A pass is a space extending from either the top section **86** to the bottom section **88** or vice versa, through which the combined strip **40** passes. In the embodiment of FIG. 1, there are ten passes **60** in the preceding heating section **52**, one pass **62** in the induction heating section **54**, and thirteen passes **64** in the following heating section **56**. While the passes in the embodiment of FIG. 1 are vertically oriented, other embodiments of the invention may have passes oriented in other directions, such as horizontal. Further embodiments of the invention may have a single horizontal pass extending from the entrance of the preceding heating section to the exit of the following heating section. In negotiating the passes, the combined strip **40** travels over rolls **70**, tensiometer rolls **72**, bridle rolls **74**, and steering rolls **76**, which are located in the top and bottom sections **86** and **88**. While all of the rolls support the combined strip **40** as it travels through the passes, some rolls have additional purposes. Tensiometer rolls **72** measure the tension in the combined strip **40** while bridle rolls **74** change the tension in it. Steering rolls **76** control the direction of the combined strip **40**.

Now referring to FIG. 2, combined strip **40**, comprising a first strip **10** and a second strip **16**, has been processed in the heating system **50**. It is understood that "strip" refers to a length of metal that is, but not limited to, at least one strip, at least one band, or at least one plate. The first strip **10** has a front end **12** and a tail end **14**. The second strip **16** has a front end **18** and a tail end **20**. The tail end **14** of first strip **10** and the front end of the second strip **16** are welded together at a transition **22**. In other embodiments of the invention, the first and second strips **10** and **16** may be attached by any other suitable means or may be unattached. In embodiments of the invention processing unattached strips, the strips are at least proximate to each other, with a region from the tail end **14** to the first end **16** being the transition **22**. Lesser portions **36** and **38** of the first and second strips **10** and **16**, respectively, are adjacent to the transition **22** and are the portions of the strips that were not heated to within approximately the peak metal temperature tolerance range. This results in the lesser portions **36** and **38** being out-of-specification material and, therefore, scrap. The remainder of first and second strips **10** and **16** are greater portions **32** and **34** of the strips, respectively. The greater portions **32** and **34** are within the peak metal temperature tolerance range and are inspecification material. A primary goal of the heating system **50** is to minimize the size of the lesser portions **36** and **38** and maximize the size of the greater portions **32** and **34**, thus maximizing the production of in-specification material.

Now referring to FIG. 3, in the preferred embodiment of the invention a programmable control mechanism **300** directs the heating of the preceding heating section **52** and the following heating section **56** and the use of the induction heating section **54**. In other embodiments of the invention, the control mechanism may not be programmable. The programmable control mechanism **300** directs the heating via a programmable control system **302** that is interconnected with the preceding heating section **52**, the induction heating section **54**, and the following heating section **56** through conduit **304** to direct the operations of the heating system **50**. In other embodiments of the invention, a wireless transmission system (not shown) may be used in place of or in conjunction with conduit **304**. Instrumentation in the heating system **50** measures at least a portion of the variables (discussed below) of the combined strip **40** and of the heating system **50** and generates variable signals **310**. Conduit **304** sends the variable signals **310** from the heating sections to the programmable control system **302**. Additional variables that are not measured by the instrumentation are determined by a heating system operator and are manually inputted into the programmable control system **302** via an input device **306**.

There are numerous variables that are received by the programmable controller **302**. Some of the variables for the first strip are length **24**, width **28**, and thickness **29**. Some of the variables for the second strip are length **26**, width **30**, and thickness **31**. Other important variables in heating the first and second strips **10** and **16** include the initial temperature of the strips, the strips' speed through the heating system **50**, and the exit temperature of the strips. Instrumentation may be used to measure a portion of these variables, i.e., thermocouples, distance indicators, speed indicators, etc.

The heating system also has variables which impact the heating of the strip, such as the temperatures in different locations of the first and following heating sections **52** and **56**. In the embodiment of FIG. 1, the first and following heating sections are divided into twelve combustion zones **101**–**112**. Other embodiments of the invention may have more or less combustion zones. At least a thermocouple (not shown) located near the middle of each zone **101**–**112** measure the zone temperatures, generate a signal **310**, and transmit that signal to the control system **302**. The preferred embodiment of the invention has two or more thermocouples in each combustion zone. Other embodiments of the invention may have different variables.

The programmable control system **302** analyzes the variable signals **310** and the manually inputted variables in the context of a thermal model **308** to determine new operating

parameters for heating system **50**. The thermal model **308** is a mathematical model that simulates the heat transfer between the heating system **50** and the combined strip **40** and the results of changes in the operating conditions of the heating system to determine new operating parameters. After the analysis, the programmable control system **302** translates the new operating parameters into operating parameter signals **312** that are sent to the heating system **50** via the conduit **304** to direct the operations thereof. In other embodiments of the invention, the operating parameters are determined by a heating system operator who either manually, or via a control system, directs the operations of the heating system **50**.

The operating parameters of the heating system **50** direct different components of the heating system. Now referring to FIGS. **1** and **4**, the heating components of the first and following heating sections **52** and **56** are gas-fired, W-type radiant tube heaters **80**. These heaters are operated in an atmosphere of 0–100% hydrogen with the balance being nitrogen or other designated prepared atmospheric gas. A tube heater **80** is comprised of a hollow tube **150** formed in the shape and orientation of a sideways "W" with a top member **152** and a bottom member **154**. A pilot burner **156** and a main gas inlet **158** extend into the top member, providing for gas **159** to enter the tube **150** and be ignited with a flame **160**, producing combustion products **162**. The pilot burner **156** is a premix-type pilot burner designed for automatic operation. The combustion products **162** travel through the interior of the tube **150** and out bottom member **154** into an exhaust gases collector **164**. As the burners are suction-type burners, exhaust fans (not shown) draw the combustion products **162** into the exhaust gases collector **164**. Air **166** enters the bottom member **154** through an air inlet **168**. The air **166** is heated by the combustion products **162** through the use of a recuperator **170** in the bottom member **154**, thereby generating 600° F. to 800° F. warmed air **172** in the preferred embodiment of the invention. The warmed air **172** travels to the top member **152** via a vertical hollow member **174** extending between the top and bottom members. The warmed air **172** is used in combusting gas **158**. Other embodiments of the invention use other types, arrangements, and amounts of heaters.

The tube heaters **80** are arranged on both sides of the passes **60** and **64** to heat the combined strip **40** as it travels therethrough. The tube heaters **80** are oriented such that the tubes **150** are parallel to the combined strip **40** as it travels through the passes. The tube heaters **80** are arranged up to approximately eleven tube heaters high on each side of a pass. The placement and control of the tube heaters **80** is designed around the twelve independent combustion zones **101–112** in the first and following heating sections **52** and **56**, as shown in FIG. **1**.

The combustion products **162** may go through additional heat recovery steps after being collected by exhaust gases collector **164**. In an embodiment of the invention, the combustion products from zones **101–112** exhaust into two separate exhaust systems. The first exhaust system exhausts zones **101–106** and the waste heat in this stream is used in the preheating section. The second exhaust system exhausts zones **107–112** and the soaking section in to a waste heat recovery system. Other embodiments of the invention may not recuperate the waste heat in the preheating zone nor in a waste heat recovery system.

The operating parameter signals **312** direct the rate of firing of the tube burners **80** by means of a control valve in the gas feed of each zone (not shown). The signals **312** also control a damper position to control negative pressure in exhaust gases collector **164** (not shown). Further, the signals **312** vary the speed of the exhaust fans to control the main suction pressure on the exhaust gases collector **164**. All of these operations result in the control of the temperatures in the combustion zones **101–112** by the control mechanism **300** through the direction of the signals **312**.

The operating parameter signals **312** also direct the components of the induction heating section **54**, which are induction heaters **82**. In the preferred embodiment of the invention, the induction heaters **82** are solenoid induction heaters. In the embodiment of the invention shown in FIG. **1**, the induction heating section **54** is comprised of five induction heaters **82** through which combined strip **40** passes. In other embodiments of the invention, the induction heating section may be a single induction heater. Induction heaters are well known in the art and are described in U.S. Pat. Nos. 4,678,883 (Saitoh, et al.), 4,585,916 (Rich), 4,054,770 (Jackson, et al.), 3,444,346 (Russell, et al.), and 2,902,572 (Lackner, et al.), which are incorporated wherein in their entireties.

In induction heater **82**, the combined strip **40** passes longitudinally through a magnetic field, inducing electrical currents therein. These induced electric currents heat the strip **40** as a result of the electric resistance of the strip. The magnetic field is generated by electrical current moving through coils in the induction heaters **82** positioned around the combined strip **40** (not shown). The control mechanism **300**, through signals **312**, directs electrical current to be supplied to the coils of the induction heaters **82**. In an embodiment of the invention, the overall length of each coil is approximately 36 inches, with a minimum of approximately 24 inches of space between adjacent coils. The inside coil dimension is approximately 8 inches by approximately 100 inches. The induction heaters **82** are cooled by a closed-loop cooling water system designed to provide a 90° F. liquid cooling medium. The cooling system comprises an evaporative type cooling tower, a cooling tower fan, a cooling tower circulation pump, and a pumping and delivery system to provide the liquid cooling medium to the induction heaters **80**. Other embodiments of the invention include different induction heaters, other configurations of induction heaters, and other means for cooling the induction heaters.

Prior to the first strip **10** entering the heating system **50**, the programmable control mechanism **300** sends operating parameter signals **312** to the first and following heating sections **52** and **56** to heat the different zones in the sections to attain a first temperature profile. The first temperature profile is established by the temperatures of the combustion zones **101–112** at which the first strip **10** can exit the heating system **50** within a predetermined first temperature tolerance range. Likewise, a second temperature profile enables the second strip **16** to exit the heating system **50** within a second predetermined temperature tolerance range. The temperature profiles are established in the first and following heating sections **52** and **56** and not the induction heating section **54** because first and following heating sections transfer heat to the strip and the heating section, which allow for temperature measurements in the heating sections and, therefore, a temperature profile which is indicative of the heat transfer to the strip in a specific zone. As the induction heaters heat the strip directly, the temperature in the induction section is not indicative of the amount of heat transfer to the metal strip and does not constitute a part of the temperature profiles established by the control mechanism **300**.

However, the programmable control mechanism **300** cannot direct the heating system **50**, or more specifically the first and following heating section **52** and **56**, to transition

between the two temperature profiles instantaneously. As long as the variables of the strips do not change appreciably, there is little need for the programmable control mechanism 300 to direct the combustion zones 101–112 to make quick changes in the temperature profile. However, the large thermal masses of the heating sections restrict the speed at which the programmable control mechanism 300 can transition the combustion zones between the two temperature profiles. The more drastic the differences in the first strip variables and the second strip variables, the greater the difference in the two temperature profiles and the slower the transition.

While the programmable control mechanism 300 is transitioning the heating system 50 between the first and second temperature profile, some of the first strip 10 and the second strip 16 exiting the heating system are not within the predetermined first or second temperature tolerance range, respectively, thereby creating relatively large lesser portions 36 and 38 and leading to more scrap strip material.

However, the programmable control mechanism 300 can direct the induction heaters 82 to quickly heat the combined strip 40, but with much higher energy costs compared to the tube heaters 80. This rapid heating is useful in supplementing the heating of the combined strip while the programmable control mechanism 300 is transitioning the heating system 50 between the two temperature profiles. This supplemental heating by the induction heating section 54 results in reduced sizes or elimination of the lesser portions 36 and 38 and lowered or eliminated amounts of out-of-specification material.

When the first strip 10 requires a hotter temperature profile than the second strip 16, the programmable control mechanism 300 starts transitioning the heating system 50 to the cooler, second temperature profile while the first strip 10 is still passing therethrough. To compensate for the increasingly cooler temperature profile of the heating system 50 and, therefore, its capability to completely heat the strip, the programmable control mechanism 300 directs the induction heating section 54 to boost the temperature of the first strip 10 so that it still exits the heating system 50 within the predetermined first temperature tolerance range. Ideally, when the transition 22 passes through the heating system 50, the programmable control mechanism 300 has completed transitioning the system between the first and second temperature profile, thereby eliminating the lesser portions 36 and 38. In practice, the lesser portions 36 and 38 may only be reduced.

When the first strip 10 requires a cooler temperature profile than the second strip 16, the programmable control mechanism 300 starts transitioning the heating system 50 to the hotter, second temperature profile while the first strip 10 is still passing therethrough. As the transition 22 passes through the heating system, the programmable control mechanism 300 supplements the heating of the second strip 16 with the induction heating section 54 until the second temperature profile is attained. This will reduce or eliminate out-ofspecification material, resulting in a minimization or an elimination of the lesser portions 36 and 38 of the first and second strips 10 and 16.

The induction heating section 54 is limited to raising the temperature of the combined strip to the metal's Curie point, which is approximately 1300° F. to 1400° F. for steel. However, the combined strip 40 requires a peak metal temperature of higher than the Curie point upon exiting the following heating section 56. Referring to FIG. 5, therefore, an aspect of the invention involves heating a metal strip to within a predetermined temperature tolerance range. The metal strip is serially traveling through a heating system 50 along a path 41 through at least one preceding heating section 52, at least one induction heating section 54, and at least one following heating section 56, with the heating sections being serially arranged as shown in FIG. 1. Typically, the length of the path 41 through the preceding heating section 52 is between approximately 40% to 50% of the length of the path through the entire heating system 50. In the first step 401, the metal strip is heated to below the Curie point in the preceding heating section. In the next step 402, the metal strip is heated to a maximum of approximately the Curie point in the induction heating section. In the following step 403, the metal strip is heated to above the Curie point in the following heating section. In the preferred embodiment of the invention, the metal strip is heated to approximately the Curie point in the induction heating section in step 402. As stated previously, the heating system may be located downstream of a preheating section and upstream of a soaking section in a continuous strip annealing line, in a continuous strip galvanizing line, or be in another process.

Another aspect of the invention is optimally locating the induction heating section 54 within heating system 50 to have a flexible and efficient heating system 50. The induction heating section's location is dictated by where being able to rapidly raise the combined strip temperature to the Curie point would be most efficient in continually producing combined strip 40 within the peak metal temperature tolerance range and, therefore, minimizing the size of the lesser portions 36 and 38 of the combined strip 40.

Referring now to FIG. 6, the determination of the location of the induction heating section is based on a design metal strip serially traveling at a design speed through the serially arranged heating sections in a pre-inductionheating-section heating system (not shown) is performed as follows. The first step 501 is to determine a plurality of design strip temperatures at a plurality of pre-induction-heating-section heating system locations, respectively. This determination may be accomplished in any suitable manner, including taking strip temperature measurements in the actual, or a similar, system or calculating theoretical temperatures for each location based on a mathematical model of the system. The next step 402 is to determine a maximum design metal strip temperature increase attainable by the design metal strip traveling through the induction heating section at the design speed. The following step 503 is to subtract the maximum design metal strip temperature increase from the Curie point of the design metal strip, thereby defining an optimum design metal strip entry temperature. The succeeding step 504 is to determine a specific system location that has a corresponding strip temperature approximately equal to the optimum design metal strip entry temperature, thereby identifying an optimum design metal strip entry location of the induction heating section. The next step 505 is to insert the induction heating section between two adjacent heating sections and proximate to the optimum design metal strip entry location. The induction heating section may be inserted either before or after the optimum design metal strip entry location, depending on how the heating sections may be separated to accommodate the induction heating section. Preferably, the sections upstream of the induction heating section, also known as the preceding heating sections, comprise approximately 40% to 50% of the heating system.

In the preferred embodiment of the invention the preceding heating section 52 comprises approximately 40% to approximately 50% of the heating system 50, and is fol-

lowed by the induction heating section 54 and the following heating section 56.

## EXAMPLE

The first strip 10 is a steel strip of 0.047" thickness and 60" width. The second strip 16 is of 0.030" thickness and 60" width. Both of these strips have a peak metal temperature tolerance range of 1550° F. ±20° F. for the strips to be in-specification. However, first strip 10 requires more heat input to raise its temperature to 1550° F. than second strip 16 due to its greater mass per length.

Now referring to FIG. 7, a graph 200 depicts a steady state heating condition of heating system 50 with the first strip 10 passing through it. On the horizontal axis 208, the percent of the length of the heating system is marked off, while the vertical axis 209 marks off temperature. The graph 200 has a first strip temperature curve 202 of the first strip 10, an ideal temperature curve 204, and a heating system temperature curve 206. The first strip temperature curve 202 is a plot of the actual temperature of the first strip at a plurality of locations in the heating system. The ideal temperature curve 204 is a plot of the ideal temperatures of first strip at a plurality of locations in the heating system. The heating system temperature curve 206 is a plot of the temperatures of the heating system at a plurality of locations in the heating system.

The heating system temperature curve 206 is 1480° F. at the entrance of the heating system and 1680° F. at the exit. The first strip and ideal temperature curves 202 and 204 are nearly superimposed, with an initial temperature of 350° F. and a peak metal temperature of 1550° F. Note that there is a flat portion 203 of the curves 202 and 204 near the middle of the heating system. The flat portion 203 corresponds to a specific location of the induction heating section 54 in the heating system which is approximately 40% of the way through the heating system. All the location preceding the induction heating section are in the preceding heating section 52 and all locations following the induction the induction heating section are in the following heating sections 56. As the induction heating section is not in use, there is no temperature change for either the actual strip or the ideal strip at the flat portion 203.

The heating system temperature curve 206 is similar to the first temperature profile. However, the heating system temperature curve 206 depicts the heating system temperatures at different locations in the heating system. The first temperature profile is distinguishable from curve 206 in that the profile is the temperatures of the heating zones 101–112 in the heating system 50 that enable the first strip 10 to be heated to within the predetermined first temperature tolerance range.

Now referring to FIG. 8, a graph 210 depicts the heating system 50 as the programmable control mechanism 300 starts to transition the temperature profile in anticipation of the second strip 16. Graph 210 has a first strip temperature curve 212, an ideal temperature curve 204, a heating system temperature curve 216, and the same axes 208 and 209 as graph 200 in FIG. 5, which are analogous to the curves in the graph 200.

The second strip 16, being significantly thinner, requires lower temperatures in preceding and following heating sections 52 and 56 to attain a peak metal temperature in the range of 1550° F. Therefore, those heating sections are starting to cool down, as shown by the system heating temperature curve 216 being only 1400° F. at the entrance and only 1620° F. at the exit. However, as strip 10 is still passing through, the induction heating section 54 is turned on, raising the first strip temperature curve 212 from 1150° F. to 1300° F. at shown at a portion 213 of the curve. Using the induction heating section 54 allows the exiting temperature of the first strip 10 to be an inspecification 1540° F.

Now referring to FIG. 9, graph 220 depicts the heating system 50 after transition 22 passes through the heating system 50 but before the heating system reaches steady state. Graph 220 has a second strip temperature curve 222, and ideal temperature curve 204, a heating system temperature curve 216, and the axes 208 and 209, which are analogous to the curves in the graphs 200 and 210.

Being thinner, the second strip temperature 222 rises quickly from 200° F. to 1200° F. in the first approximately 40% of the heating system. Since the induction heaters 80 are turned off, the second strip temperature curve 222 is flat at a portion 223, which corresponds to the induction heating section 54. The curve 222 continues to climb to an exit temperature of 1570° F., which is within specification. In this example, the size of the lesser portions 36 and 38 were essentially eliminated. In other transitions, the sizes of the lesser portions only be reduced.

Now referring to FIG. 10, graph 230 depicts a heating system 50 at a steady state with the second strip 16 passing through it. Graph 230 has a second strip temperature curve 232, an ideal temperature curve 204, a heating system temperature curve 236, and the axes 208 and 209, which are analogous to the curves in the graphs 200, 210, 220.

The heating system temperature curve 236 is lower than the curves 206 and 216 as the second strip 16 requires less heat input than the first strip 10 due to its relative thinness. The temperature of the curve 236 is 1280° F. at the entrance to the heating system, compared to 1480° F. for the curve 206. Likewise, the temperature of the curve 236 is 1600° F. at the exit of the heating system, compared to 1680° F. for the curve 206. Since the induction heaters 80 are turned off, the second strip temperature curve 232 is flat at a portion 233 which corresponds with the location of the induction heating section 54.

The heating system temperature curve 236 is similar to the second temperature profile. However, the heating system temperature curve 236 depicts the heating system temperatures different locations in the heating system. The second temperature profile is distinguishable from the curve 236 in that the profile is the temperatures of the heating zones 101–112 in the heating system 50 that enable the second strip 16 to be heated to within the predetermined second temperature tolerance range.

Therefore, by placing the induction heating section 54 between the first and following heating sections 52 and 56 of a heating system 50, a greater percentage of the combined strip 40 exits the heating system 50 within the peak metal temperature tolerance range, thereby minimizing the lesser portions 36 and 38 of the combined strip. Other embodiments of the invention may heat a strip of more than two strips.

The present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof and, accordingly, reference should be made to the appended claims, rather than to the foregoing specification, as indicating the scope of the invention.

We claim:

1. A method of heating a metal strip to within a predetermined temperature tolerance range while the metal strip serially travels through a path in a heating system, the method comprising the steps of:

providing a heating system comprising at least one preceding heating section, at least one induction heating section, and at least one following heating section which are serially arranged;

locating the heating system downstream of a preheating section and upstream of a soaking section in a continuous strip annealing line, in a continuous strip galvanizing line, or in a continuous plate furnace;

heating the metal strip to below the Curie point in the preceding heating section;

heating the metal strip to a maximum of approximately the Curie point; and

heating the metal strip to above the Curie point.

2. The method of claim 1, wherein the path has a length and a portion that extends through the preceding heating section, the portion having a length of approximately 40% to 50% of the length of the path.

3. A method of optimally locating an induction heating section in a pre-induction-heating-section heating system comprised of a plurality of serially arranged heating sections for heating a design metal strip serially traveling at a design speed therethrough along a path, comprising the steps of:

a) determining a plurality of strip temperatures at a plurality of system locations in the pre-induction-heating-section heating system, respectively;

b) determining a maximum design metal strip temperature increase attainable by the design metal strip traveling through the induction heating section at the design speed;

c) subtracting the maximum design metal strip temperature increase from a Curie point of the design metal strip, thereby defining an optimum design metal strip entry temperature;

d) determining a specific system location that has a corresponding strip temperature approximately equal to the optimum design metal strip entry temperature, thereby identifying an optimum design metal strip entry location; and

e) inserting the induction heating section between two adjacent heating sections and proximate to the optimum design metal strip entry location.

4. The method of claim 3, further comprising the step of inserting the induction heating section before or after the optimum design metal strip entry location.

5. The method of claim 3, further comprising the step of inserting the induction heating section after one or more preceding heating sections of the heating system, wherein the path has a length and a portion that extends through the preceding heating section, the portion having a length of approximately 40% to 50% of the length of the path after inserting the induction heating section therein.

6. A method of heating a first and a second metal strip to within a predetermined first and second temperature tolerance range, respectively, each metal strip having a beginning portion, an ending portion, a front edge and a tail edge, the tail edge of the first metal strip being at least proximate to the front edge of the second metal strip, comprising the steps of:

a) providing a heating system comprising at least one preceding heating section, an induction heating section, and at least one following heating section serially arranged;

b) serially passing the first and second metal strips through the heating system;

c) while the beginning portion of the first metal strip is passing through the heating system, heating the preceding and following heating sections to a first temperature profile;

d) while the first metal strip ending portion and the second metal strip beginning portion are passing through the heating system, transitioning the heating of the preceding and following heating sections to attain a second temperature profile therein, including supplementing the heating of first metal strip ending portion and/or the second metal strip beginning portion with the induction heating section; and

e) while the ending portion of the second metal strip is passing through the heating system, heating the preceding and following heating sections to the second temperature profile.

7. The method of claim 6, wherein the the tail edge of the first metal strip being attached to the front edge of the second metal strip.

8. The method of claim 7, further comprising the steps of:

a) inputting first metal strip variables, second metal strip variables, and heating system variables into a control system; and

b) directing the operation of the preceding heating section, the induction heating section, and following heating section based on the predetermined first and second temperatures, a thermal model, the first metal strip variables, the second metal strip variables, and the heating system variables with the control system.

9. The method of claim 8, wherein the directing and/or the inputting steps are at least partially performed by a heating system operator.

10. The method of claim 8, wherein:

a) the first metal strip variables comprise length, width, thickness, strip speed through the heating system, initial strip temperature and final strip temperature;

b) the second metal strip variables comprise length, width, thickness, strip speed through the heating system, initial strip temperature and final strip temperature; and

c) the heating system variables comprise an actual temperature profile of the preceding and following heating sections.

11. The method of claim 10, wherein the inputting step further comprises the steps of:

a) measuring at least a portion of the first metal strip variables, at least a portion of the second metal strip variables, and at least a portion of the heating system variables with instrumentation;

b) generating variable signals therefrom; and

c) transmitting the variable signals to the control system.

12. The method of claim 9, wherein the serially passing step further comprises passing the first and second metal strips serially through;

a) a plurality of heaters arranged in passes in the preceding heating section;

b) at least an induction heater arranged in at least a pass; and

c) a plurality of heaters arranged in passes in the following heating section.

13. The method of claim 12, wherein the passes are vertically or horizontally oriented.

14. The method of claim 12, wherein the heaters of the preceding and following heating sections are gas-fired W-type radiant tubes.

15. The method of claim 7, further comprising the step of passing the first and second metal strips through a soaking section of a continuous strip annealing line after serially passing the first and second metal strips through the heating system step.

16. A heating system for heating a first and a second metal strip to within a predetermined first and second temperature tolerance range, respectively, each metal strip having a beginning portion, an ending portion, a front edge and a tail edge, the tail edge of the first metal strip being at least proximate to the front edge of the second metal strip, comprising:

a) at least one preceding heating section;

b) an induction heating section;

c) at least one following heating section, wherein the heating sections are serially arranged to enable the first and second metal strips to serially pass therethrough; and

d) a metal strip temperature control mechanism connected to the first, induction, and following heating sections for:

(i) attaining a first temperature profile in the preceding and following heating sections;

(ii) attaining a second temperature profile in the preceding and following heating sections; and

(iii) supplementally heating the first metal strip ending portion and/or the second metal strip beginning portion in the induction heating section while transitioning the preceding and following heating sections between the first and second temperature profiles.

17. The heating system of claim 16, wherein the the tail edge of the first metal strip being attached to the front edge of the second metal strip.

18. The heating system of claim 17, wherein the metal strip temperature control mechanism comprises:

a) inputting means for inputting first metal strip variables, second metal strip variables, and heating system variables into a control system; and

b) a thermal model; wherein, the control system directs the operation of the heating sections based on the predetermined first and second temperatures, the thermal model, first metal strip variables, second metal strip variables, and heating system variables.

19. The heating system of claim 18, wherein:

a) the first metal strip variables comprise length, width, thickness, strip speed through the heating system, initial strip temperature and final strip temperature of the first metal strip;

b) the second metal strip variables comprise length, width, thickness, strip speed through the heating system, initial strip temperature and final strip temperature of the second metal strip; and

c) the heating system variables comprise an actual temperature profile of the preceding and following heating sections.

20. The heating system of claim 19, wherein:

a) the preceding and following heating sections comprise a plurality of heaters arranged in passes;

b) the induction heating section comprises at least an induction heater arranged in at least a pass; and

c) the heating section passes are serially arranged to enable the first and second metal strips to pass serially therethrough.

21. The heating system of claim 20, wherein the passes are vertically or horizontally oriented.

22. The system of claim 21, wherein the heaters of the preceding and following heating sections are gas-fired, W-type radiant tubes.

23. The heating system of claim 22, wherein:

a) the inputting means comprises instrumentation for measuring at least a portion of the first metal strip variables, at least a portion of the second metal strip variables, and at least a portion of the heating system variables, generating variable signals therefrom, and sending the variable signals to the control system; and

b) the control system comprises means for receiving the variable signals.

24. The heating system of claim 18, wherein the control system is programmable.

25. The heating system of claim 17, wherein the heating system is located:

a) downstream of a preheating section and upstream of a soaking section in a continuous strip annealing line;

b) in a continuous strip galvanizing line; or

c) in a continuous plate furnace.

26. The heating system of claim 17, wherein the metal strip temperature control mechanism is at least partially controllable by a heating system operator.

* * * * *

US-PAT-NO: 5401941

DOCUMENT-IDENTIFIER: US 5401941 A

TITLE: Apparatus for the inductive cross-field heating of flat material

---------- KWIC ---------

Brief Summary Text - BSTX (18):

In accordance with a concomitant feature of the invention, there is provided a temperature-profile measuring device for **recording** a temperature profile of the flat material after inductive cross-field heating has taken place, and a position controller receiving the temperature profile from the measuring device, receiving a predetermined desired profile and controlling the drive devices for adjusting the position of the induction loops independently of deviations between the **recorded** temperature profile and the predetermined desired profile.

Detailed Description Text - DETX (14):

The drive devices 25, 31 of the induction modules C, D and drive devices 41, 42 of the induction modules E, F may be electrical or hydraulic, for example, and are shown diagrammatically. It is essential that the induction modules always be used in pairs in an induction installation and, inter alia, depending

on the temperature to be achieved in the flat material and on the run-through speed of the flat material, either only one pair of induction modules can be provided or a plurality of pairs of induction modules can be used. A temperature profile T of the flat material 1 heated by the induction modules is **recorded** by means of a temperature-profile measuring device 43 and is fed to a position controller 44. If the **recorded** temperature profile T differs from a predetermined desired profile Tdes, that is to say if the temperature is non-uniform perpendicularly to the direction of movement y of the flat material, then during operation, the position controller 44 transmits corresponding control signals S1, S2, S3, S4 to the drive devices 25, 31, 41, 42 of the induction modules C, D, E, F, with the result that a change in the fine positioning of the individual induction loops of the modules takes place with the aim of making the temperature profile uniform over the width of the flat material. For this reason, the control signals S1 to S4 are fed not only to the driving devices for the upper induction loops, but of course they are fed in the same way to the drive devices for the lower induction loops (such as the drive devices 26, 32 according to FIGS. 4 and 5).

Claims Text - CLTX (13):
9. The apparatus according to claim 8, including a temperature-profile measuring device for **recording** a temperature profile of the flat material after

US005401941A

# United States Patent [19]

[11] Patent Number: 5,401,941

Mauve et al.

[45] Date f Patent: Mar. 28, 1995

[54] APPARATUS FOR THE INDUCTIVE CROSS-FIELD HEATING OF FLAT MATERIAL

[75] Inventors: Hans W. Mauve; Wolfgang Andree, both of Lünen, Germany

[73] Assignee: ABB Patent GmbH, Mannheim, Germany

[21] Appl. No.: 136,441

[22] Filed: Oct. 13, 1993

[30] Foreign Application Priority Data

Oct. 13, 1992 [DE] Germany ........ 42 34 406.9

[51] Int. Cl.$^6$ ........ H05B 6/40

[52] U.S. Cl. ........ 219/645; 219/656; 219/670; 219/667; 219/673

[58] Field of Search ........ 219/645, 656, 646, 671, 219/670, 667, 673, 675

[56] References Cited

U.S. PATENT DOCUMENTS

| | | | |
|---|---|---|---|
| 3,444,346 | 5/1969 | Russell et al. . | |
| 3,705,285 | 12/1972 | Cachat . | |
| 4,357,512 | 11/1982 | Nishimoto et al. | 219/667 |
| 4,708,325 | 11/1987 | Georges | 219/645 |
| 4,788,396 | 11/1988 | Maugein et al. | 219/645 |
| 4,891,484 | 1/1990 | Waggott et al. | 219/645 |
| 5,156,683 | 10/1992 | Ross | 219/645 |

FOREIGN PATENT DOCUMENTS

| | | |
|---|---|---|
| 0246660 | 11/1987 | European Pat. Off. . |
| 119820 | 5/1976 | Germany . |
| 2155740 | 9/1985 | United Kingdom . |
| 396394 | 8/1973 | U.S.S.R. . |
| 1073902 | 2/1984 | U.S.S.R. . |
| 8501532 | 4/1985 | WIPO . |

OTHER PUBLICATIONS

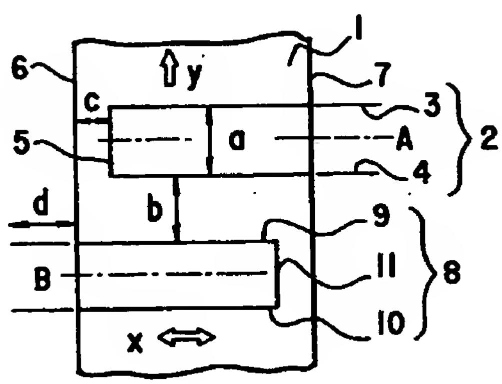
Metall Publ. Aug. 1989, pp. 750–754, Wilden et al. "Induktive Hochleistungsglühanlagen Für Die Kont," German Search Report.

*Primary Examiner*—Philip H. Leung
*Attorney, Agent, or Firm*—Herbert L. Lerner; Laurence A. Greenberg

[57] ABSTRACT

An apparatus for the inductive cross-field heating of flat material includes a plurality of mutually opposite induction loops being disposed above and below the flat material. At least one pair of induction modules is formed of two induction modules being adjustable independently of one another in their position relative to the flat material. Each induction module has two mutually opposite U-shaped induction loops having geometries and dimensions which are invariable, base legs which can be positioned in such a way that they terminate at least a predeterminable distance in front of one edge of the flat material and within the width of the flat material, and two side legs which can be positioned in such a way that they project at least a predeterminable distance beyond the other edge of the flat material. The induction loops of the two induction modules of a pair of induction modules are open towards oppositely directed sides, with the result that the side legs of only one induction loop project beyond each edge of the flat material.

10 Claims, 2 Drawing Sheets



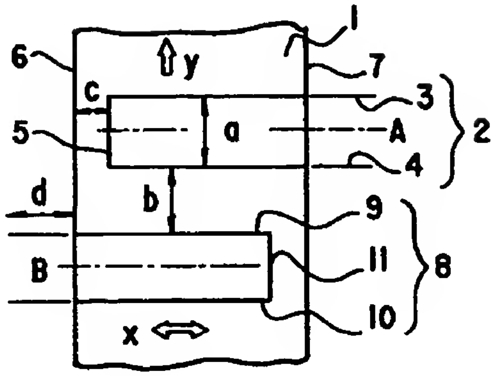



Fig.1

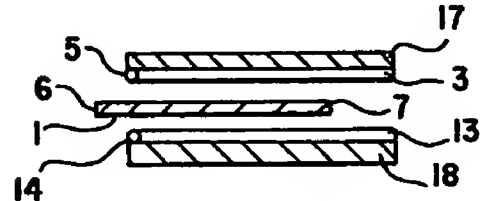



Fig.2

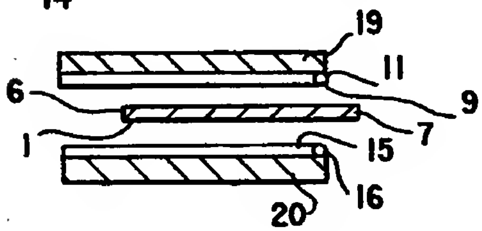



Fig.3

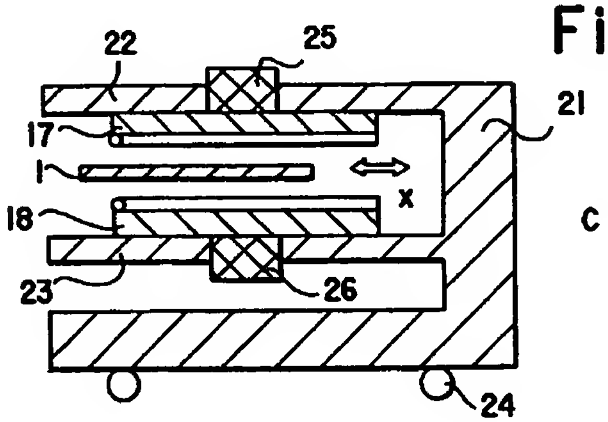



Fig.4

C

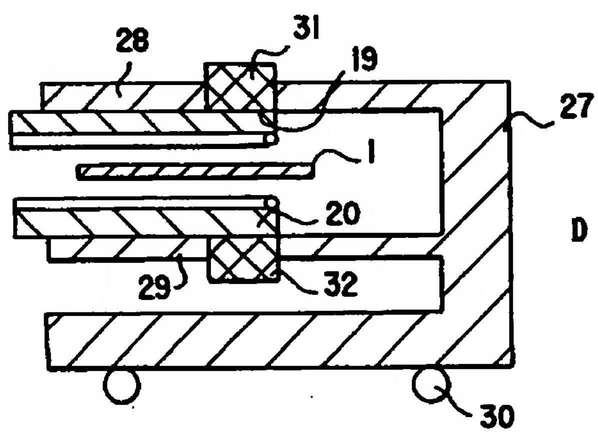
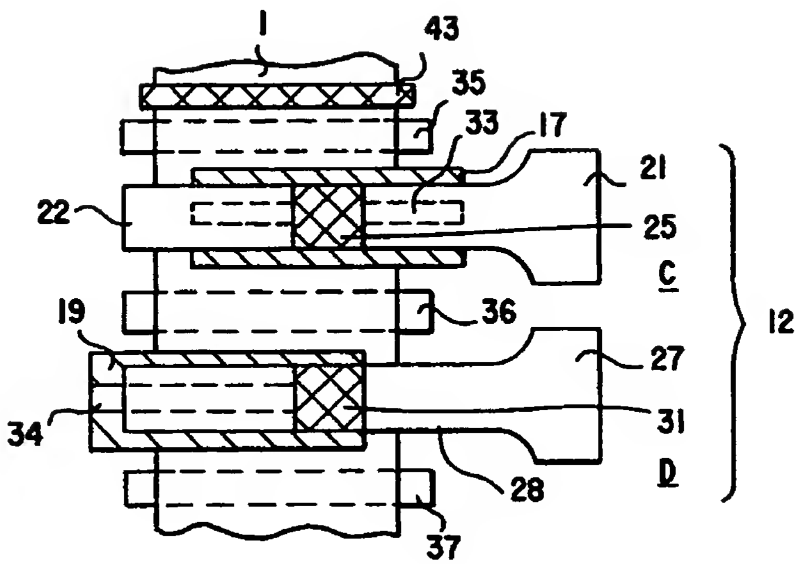



Fig.5

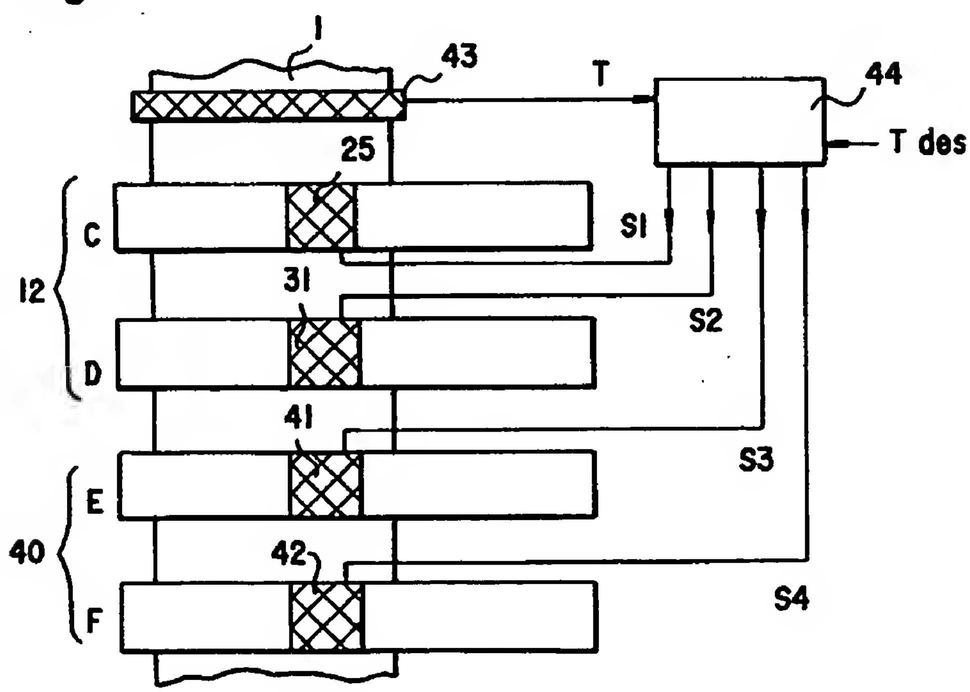
D

Fig.6



1
43
35
33
17
21
22
25
C
36
12
19
27
34
31
28
D
37


Fig.7



1
43
T
44
T des
25
C
S1
12
31
S2
D
41
S3
E
40
42
S4
F

## APPARATUS FOR THE INDUCTIVE CROSS-FIELD HEATING OF FLAT MATERIAL

### BACKGROUND OF THE INVENTION

#### FIELD OF THE INVENTION

The invention relates to an apparatus for the inductive cross-field heating of flat material, including a plurality of mutually opposite induction loops being disposed above and below the flat material, some of the induction loops projecting beyond the edges of the flat material, and others of the induction loops terminating within the width of the flat material.

Such an apparatus for the inductive cross-field heating of flat material is known from Published European Application No. 0 246 660. There, an overall configuration being formed of main coils and auxiliary coils is proposed. The main coils are disposed perpendicularly to the direction of movement of the flat material and project beyond the two outer edges of the flat material. The auxiliary coils extend parallel to the direction of movement of the flat material and are disposed in the vicinity of the edges of the flat material, but without projecting beyond them. The combination of main and auxiliary coils achieves a uniform temperature profile over the entire width of the flat material. The main coils in particular heat the middle region and the two immediate edge regions of the flat material, but zones of lower temperature occur in the vicinity of the edges and parallel to them. The zones in the vicinity of the edges are reheated by the auxiliary coils, so that the necessary uniform temperature distribution is established over the entire width of the flat material.

Since the main coils and in particular also the auxiliary coils have to be matched to the width of the flat material to be heated, mechanical devices must be provided for adjusting the coil width. The auxiliary coils in particular must be capable of being matched exactly to the width of the flat material, in order to reheat the zones of lower temperatures in the vicinity of the edges and parallel thereto in the desired way. The matching of the main and auxiliary coils to the width of the flat material is complicated and labor-intensive. If a non-uniform and unsatisfactory temperature profile is measured over the: width of the flat material during the cross-field heating, no readjustment is possible during operation.

### SUMMARY OF THE INVENTION

It is accordingly an object of the invention to provide an apparatus for the inductive cross-field heating of flat material, which overcomes the hereinafore-mentioned disadvantages of the heretofore-known devices of this general type, which can be used universally for flat material of differing width and which allows a rapid matching to the desired width of flat material and to the heating capacity required.

With the foregoing and other objects in view there is provided, in accordance with the invention, an apparatus for the inductive cross-field heating of flat material, comprising at least one pair of induction modules being adjustable in position independently of one another relative to a flat material to be heated, the flat material having edges defining a width; each of the induction modules including two mutually opposite U-shaped induction loops having invariable geometries and dimensions and being disposed above and below the flat material, the induction loops having base legs to be positioned for terminating at least at a predeterminable distance in front of one of the edges of the flat material and within the width of the flat material, and the induction loops having two side legs to be positioned for projecting at least at a predeterminable distance beyond the other of the edges of the flat material; and the induction loops of the pair of the induction modules being open towards oppositely directed sides with the side legs of the induction loops each projecting beyond a respective one of the edges of the flat material.

The advantages which can be afforded by the invention are, in particular, that the apparatus for the inductive cross-field heating of flat material can be matched in a very flexible way to different parameters of the flat material and of the induction process, such as the width, thickness, entry temperature and run-through speed of the flat material. The induction modules are all constructed identically and are dimensioned in such a way that a respective induction module can be pushed in between two support rollers serving to support the flat material. Matching to the width of the flat material is carried out by displacing the modules perpendicularly to the direction of run-through movement of the flat material, in such a way that the base legs of the induction loops are disposed above the zones in the vicinity of the edges of the flat material, at which too low a temperature would occur if heating took place solely by means of the side legs projecting beyond the edges of the flat material. The geometrical configuration of the induction loops of the modules does not have to be varied for this purpose. Advantageously, all of the induction modules reach over the flat material from only one side, so that a feed of the flat material into the apparatus for inductive cross-field heating and extraction therefrom are possible in a very simple way. The mechanical mounting of the structural components carrying the induction loops and the electrical energy supply of the induction loops take place from one side. The identical construction of the induction modules results in price benefits in production and in benefits with regard to the maintenance of stock of replacement parts. Only one type of induction module need be planned, produced and kept in stock for different uses.

The number of pairs of induction modules used in an installation for the inductive heating of flat material depends on the thickness, width, entry temperature and run-through speed of the flat material and on the temperature to be achieved in the flat material.

Furthermore, the advantages which can be afforded by the apparatus for the inductive cross-field heating of flat material are that the positions of the induction loops can be varied independently of one another during operation for optimization purposes, with the effect of fine adjustment, in order to obtain as uniform a temperature profile as possible over the width of the flat material.

In accordance with another feature of the invention, each of the induction modules has a framework with an upper supporting arm and a lower supporting arm for mounting the two induction loops.

In accordance with a further feature of the invention, there are provided lamination bundles each being associated with a respective one of the induction loops for mounting the induction loops on the frameworks.

In accordance with an added feature of the invention, there are provided means associated with the frameworks for varying the position of the induction loops relative to the flat material.

In accordance with an additional feature of the invention, the induction loops are adjustable relative to the supporting arms.

In accordance with yet another feature of the invention, there are provided lamination-bundle suspensions on the supporting arms serving as guide means for adjusting the induction loops.

In accordance with yet a further feature of the invention, there are provided drive devices for adjusting the induction loops.

In accordance with a concomitant feature of the invention, there is provided a temperature-profile measuring device for recording a temperature profile of the flat material after inductive cross-field heating has taken place, and a position controller receiving the temperature profile from the measuring device, receiving a predetermined desired profile and controlling the drive devices for adjusting the position of the induction loops independently of deviations between the recorded temperature profile and the predetermined desired profile.

Other features which are considered as characteristic for the invention are set forth in the appended claims.

Although the invention is illustrated and described herein as embodied in an apparatus for the inductive cross-field heating of flat material, it is nevertheless not intended to be limited to the details shown, since various modifications and structural changes may be made therein without departing from the spirit of the invention and within the scope and range of equivalents of the claims.

The construction and method of operation of the invention, however, together with additional objects and advantages thereof will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a fragmentary, diagrammatic, top-plan view of a flat material with two induction loops;

FIGS. 2 and 3 are longitudinal-sectional views respectively taken along section lines A and B of the configuration according to FIG. 1;

FIGS. 4 and 5 are longitudinal-sectional views through induction modules;

FIG. 6 is a fragmentary, top-plan view of a flat material with two induction modules; and

FIG. 7 is a fragmentary, top-plan view of a basic regulating device for the induction modules.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the figures of the drawing in detail and first, particularly, to FIG. 1 thereof, there is seen a top view of a flat material having two induction loops (with lamination bundles removed). FIG. 1 illustrates a flat material 1 to be heated, preferably a strip of a material which can be influenced inductively, and above which two upper induction loops 2, 8, each having an invariable geometrical shape, are disposed. The upper induction loop 2 of a first induction module is formed of two parallel side legs 3 and 4 being directed perpendicularly to a direction of movement y of the flat material 1 and having a pole distance a, and a base leg 5 connecting the two side legs at right angles. It is essential that the base leg 5 be located above the flat material at a predetermined distance c from a first edge 6 of the flat material 1. In other words, under no circumstances does the base leg 5 project beyond the flat material itself. However, the side legs 3, 4 project beyond a second edge 7 of the flat material 1 at least by a predetermined projecting length d, that is to say the actual projection can exceed this length d, but under no circumstances can it fall short of it.

The upper induction loop 8 of a second induction module, which is located at a distance from the upper induction loop 2 of the first induction module, is likewise formed of two parallel side legs 9 and 10 being directed perpendicularly to the direction of movement y of the flat material 1 and having the pole distance a, and a base leg 11 connecting the two side legs 9, 10 at right angles. At the same time, the base leg 11 is located above the flat material 1 and at the distance c from the second edge 7 of the flat material, without projecting beyond the second edge 7 itself. However, the side legs 9, 10 project beyond the first edge 6 of the flat material at least by the projecting length d.

As can be seen, each induction loop projects beyond only one edge of the flat material 1. The side legs 3, 4 heat the middle region of the flat material 1 and its edge 7. The side legs 9, 10 heat the edge 6 of the flat material and likewise the middle region. The base leg 5 serves for heating the zone in the vicinity of and parallel to the edge 6. The base leg 11 heats the zone in the vicinity of and parallel to the edge 7.

FIGS. 2 and 3 show sections through the configuration according to FIG. 1. The configuration according to FIG. 2 is a section taken along the line A according to FIG. 1, and the configuration according to FIG. 3 is a section taken along the line B according to FIG. 1.

The flat material 1 with its two edges 6, 7 can be seen in the two FIGS. 2 and 3. Furthermore, FIG. 2 illustrates the side leg 3, the base leg 5 and a lamination bundle 17 of the upper induction loop 2 of the first induction module. Located underneath the upper induction loop 2 is an identically constructed lower induction loop, of which a first side leg 13, a base leg 14 and a lamination bundle 18 can be seen. The distances a, c, d defined for the upper induction loop 2 also apply to the lower induction loop.

FIG. 3 illustrates the side leg 9, the base leg 11 and the lamination bundle 19 of the upper induction loop 8 of the second induction module. Below this upper induction loop is located an identically constructed lower induction loop, of which a first side leg 15, a base leg 16 and a lamination bundle 20 can be seen. The distances a, c, d defined for the upper induction loop 8 also apply to the lower induction loop. The induction loops are preferably fixedly connected to the associated lamination bundles.

FIGS. 4 and 5 show sections through two induction modules. An induction module C shown in FIG. 4 has the induction loops described in detail above with regard to FIGS. 1 and 2, together with the lamination bundles 17, 18. An induction module D shown in FIG. 5 has the induction loops described in particular above with regard to FIGS. 1 and 3, together with the lamination bundles 19, 20. Each induction module is formed of a framework with respective upper and lower supporting arms for fastening the induction-loop/lamination-bundle configurations. The positioning of the induction modules relative to the flat material 1 in a direction x perpendicular to the direction of movement y of the flat material is made possible in a simple way. In order to provide approximate positioning, the frameworks of the induction modules are provided, for example, with lockable rollers, as a result of which the position setting

of the induction loops in relation to the flat material can take place due to the displacement of the induction modules themselves. In order to provide fine positioning, drive devices are provided on the upper and lower supporting arms of the frameworks for allowing a continuous adjustment of the lamination bundles and therefore of the induction loops in relation to the flat material, with the position of the induction modules relative to the flat material remaining unchanged and only a variation in position between the supporting arms and the lamination bundles/induction loops taking place.

In particular, the induction module C according to FIG. 4 has a framework 21 with an upper supporting arm 22, a lower supporting arm 23 and rollers 24 for approximate positioning. A drive device 25 fastened to the upper supporting arm 22 serves for the fine positioning of the lamination bundle 17 and therefore of the upper induction loop. A drive device 26 fastened to the lower supporting arm 23 serves for the fine positioning of the lamination bundle 18 and therefore of the lower induction loop.

It is evident from FIG. 5 that the induction module D has a framework 27 with an upper supporting arm 28, a lower supporting arm 29 and rollers 30 for approximate positioning. A drive device 31 fastened to the upper supporting arm 28 serves for the fine positioning of the lamination bundle 19 and therefore of the upper induction loop. A drive device 32 fastened to the lower supporting arm 29 serves for the fine positioning of the lamination bundle 20 and therefore of the lower induction loop.

FIG. 6 shows a top view of a flat material to be heated, together with two induction modules. The induction module C with the framework 21, the upper supporting arm 22 and the drive device 25 as well as the induction module D with the framework 27, the upper supporting arm 28 and the drive device 31 can be seen. In order to fasten the lamination bundles 17 and 19 to the supporting arms 22 and 28, the lamination bundles 17 and 19 are provided with respective lamination-bundle suspensions. 33 and 34 which are mounted movably in corresponding suspension devices of the supporting arms and into which the drive devices 25 and 31 engage force-lockingly. A force-locking connection is one which connects two elements together by force external to the elements, as opposed to a form-locking connection which is provided by the shapes of the elements themselves.

As can be seen, each of the induction modules C, D is located between two respective support rollers 35, 36 and 36, 37 which are provided for holding the flat material 1, so that the distance b between the induction loops of the two adjacent induction modules is predetermined by the distance between these support rollers. The two induction modules C, D form a first pair of induction modules 12.

FIG. 7 illustrates a basic position-regulating device for the induction modules. The pair of induction modules 12 and a pair of induction modules 40 are provided in the example. The pair of induction modules 12 includes the induction modules C and D and the pair of induction modules 40 includes induction modules E and F. The use of further pairs of induction modules is possible, with each pair of induction modules being constructed in the same way as described above with regard to FIGS. 1 to 6.

The drive devices 25, 31 of the induction modules C, D and drive devices 41, 42 of the induction modules E, F may be electrical or hydraulic, for example, and are shown diagrammatically. It is essential that the induction modules always be used in pairs in an induction installation and, inter alia, depending on the temperature to be achieved in the flat material and on the run-through speed of the flat material, either only one pair of induction modules can be provided or a plurality of pairs of induction modules can be used. A temperature profile T of the flat material 1 heated by the induction modules is recorded by means of a temperature-profile measuring device 43 and is fed to a position controller 44. If the recorded temperature profile T differs from a predetermined desired profile Tdes, that is to say if the temperature is non-uniform perpendicularly to the direction of movement y of the flat material, then during operation, the position controller 44 transmits corresponding control signals S1, S2, S3, S4 to the drive devices 25, 31, 41, 42 of the induction modules C, D, E, F, with the result that a change in the fine positioning of the individual induction loops of the modules takes place with the aim of making the temperature profile uniform over the width of the flat material. For this reason, the control signals S1 to S4 are fed not only to the driving devices for the upper induction loops, but of course they are fed in the same way to the drive devices for the lower induction loops (such as the drive devices 26, 32 according to FIGS. 4 and 5).

We claim:

1. An apparatus for the inductive cross-field heating of flat material, comprising:

at least one pair of induction modules being adjustable in position independently of one another relative to a flat material to be heated, said induction modules defining a flat region for receiving the flat material to be heated,

said flat region having edges defining a width corresponding to a width of the flat material;

each of said induction modules including two mutually opposite U-shaped induction loops having invariable geometries and dimensions and being disposed above and below said flat region, said induction loops having base legs positioned a predetermined distance from one of said edges of said flat region and within said width of said flat region, and said induction loops having two side legs projecting a predetermined distance beyond the other of said edges of said flat region; and

said induction loops of said pair of said induction modules being open towards oppositely directed sides and only said side legs of said induction loops each projecting beyond a respective one of said edges of said flat region.

2. The apparatus according to claim 1, wherein each of said induction modules has a framework with an upper supporting arm and a lower supporting arm for mounting said two induction loops.

3. The apparatus according to claim 2, including lamination bundles each being associated with a respective one of said induction loops for mounting said induction loops on said framework.

4. The apparatus according to claim 3, including means associated with said frameworks for varying the position of said induction loops relative to the flat material.

5. The apparatus according to claim 2, including means associated with said frameworks for varying the position of said induction loops relative to the flat material.

6. The apparatus according to claim 2, wherein said induction loops are adjustable relative to said supporting arms.

7. The apparatus according to claim 6, including lamination-bundle suspensions on said supporting arms serving as guide means for adjusting said induction loops.

8. The apparatus according to claim 7, including drive devices for adjusting said induction loops.

9. The apparatus according to claim 8, including a temperature-profile measuring device for recording a temperature profile of the flat material after inductive cross-field heating has taken place, and a position controller receiving the temperature profile from said measuring device, receiving a predetermined desired profile and controlling said drive devices for adjusting the position of said induction loops independently of deviations between the recorded temperature profile and the predetermined desired profile.

10. An apparatus for the inductive cross-field heating of flat material, comprising:

flat material to be inductively heated traveling through the apparatus, said flat material having a width and first and second edges bounding said flat material;

a pair of induction modules, said pair of induction modules being adjustable in position independently of one another relative to said flat material;

each induction module of said pair being formed by two U-shaped, mutually opposite induction loops respectively disposed above and below said flat material; said induction loops having invariable geometries and dimensions; said induction loops having base legs being positionable a predetermined distance from said first edge of said flat material within said width of said flat material; and said induction loops having two side legs projecting a predetermined distance beyond said second edge of said flat material; and

only said side legs of said induction loops projecting beyond a respective one of said first and second edges of said flat material.

* * * * *

US-PAT-NO: 3567895

DOCUMENT-IDENTIFIER: US 3567895 A
**See image for Certificate of Correction**

TITLE: TEMPERATURE CONTROL SYSTEM

---------- KWIC ---------

Detailed Description Text - DETX (86):
Thus, the apparatus includes epitaxial reactor 50 whose temperature is controlled by means of analogue controller 51 and a control thermocouple 52 via the RF generator. It further includes a measuring system consisting of a measurement thermocouple 53 embedded in a carbon boat 58 and the optical sensors, radiation pyrometer 54, prism 56, and optical pyrometer 55. The recording system consists of a plata aquisition system, such as an IBM 1800 Computer 57, **program** controlled to sample the points and list the results.

Detailed Description Text - DETX (155):
The software required to implement the control algorithm is a part of a larger DPC **program** that is utilized to control temperature, flow and other process variables. Given the prior information and desired result, a **programmer** skilled in the art can **program** the computer. Thus, heating means other than RF may be used, such as electrical resistance or gas, for example.

# United States Patent

[11] 3,567,895


[72] Inventor Oded Paz
Poughkeepsie, N.Y.


[21] Appl. No. 849,029
[22] Filed Aug. 11, 1969
[45] Patented Mar. 2, 1971
[73] Assignee International Business Machines Corporation
Armonk, N.Y.


[54] **TEMPERATURE CONTROL SYSTEM**
16 Claims, 17 Drawing Figs.


[52] U.S. Cl. .......... 219/10.77, 219/10.43
[51] Int. Cl. .......... H05b 9/06, H05b 5/00
[50] Field of Search .......... 219/10.77, 497, 10.43, 10.57, 10.71, 10.79, 10.75; 23/273, 301; 236/78 (B), 15 (B); 203/2


[56] References Cited

UNITED STATES PATENTS


| | | | |
|---|---|---|---|
| 2,813,186 | 11/1957 | Bock .......... | 219/10.61 |
| 2,916,593 | 12/1959 | Herrick .......... | 219/10.77X |
| 2,992,311 | 7/1961 | Keller .......... | 219/10.77 |
| 3,097,283 | 7/1963 | Giacchetti .......... | 219/10.77 |
| 3,136,876 | 6/1964 | Crosthwait .......... | 219/10.77 |
| 3,150,064 | 9/1964 | Dobson .......... | 202/206 |
| 3,174,298 | 3/1965 | Kleiss .......... | 62/211 |
| 3,180,974 | 4/1965 | Darling .......... | 219/497 |



*Primary Examiner*—J. V. Truhe
*Assistant Examiner*—L. H. Bender
*Attorneys*—Hanifin and Jancin and Melvyn D. Silver



**ABSTRACT:** A temperature control system useful for epitaxial growth of silicon wafers in a reactor comprising in one embodiment an RF feedback loop and two temperature feedback loops, e.g. a thermocouple loop and an optical sensor loop. The structure and method disclosed generate error signals so that correctional factors sequentially derived, in cascade form from the optical sensor loop, the thermocouple loop and the RF loop, provide a resultant signal employed to correct the reactor temperature.

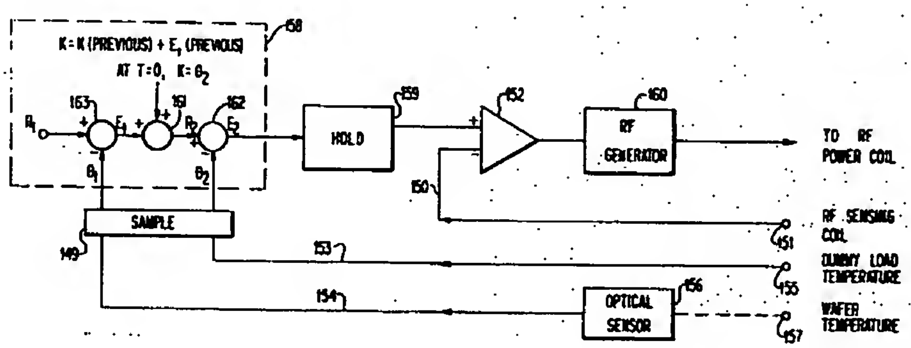



FIG. 1
PRIOR ART

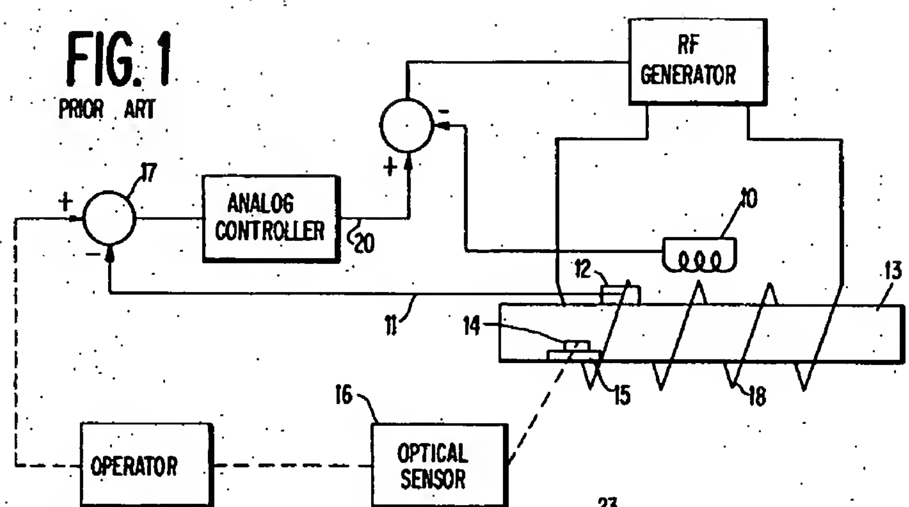
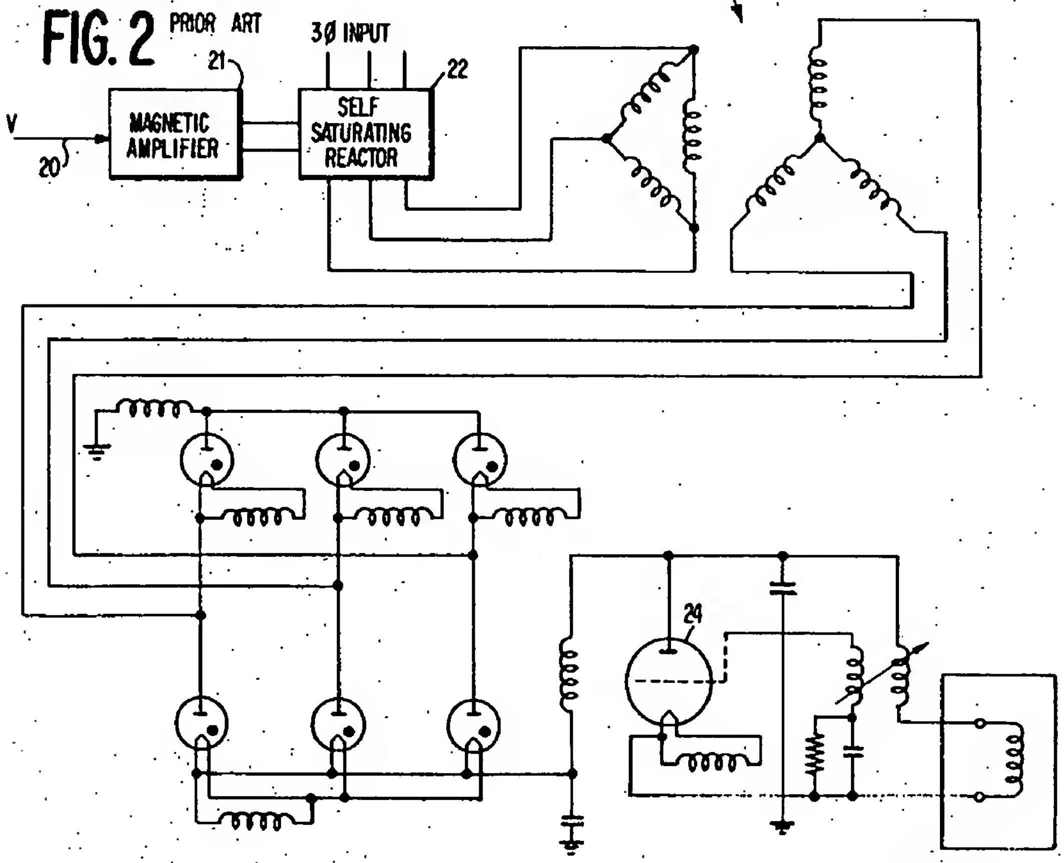



FIG. 2 PRIOR ART




INVENTOR
ODED PAZ

BY Melvyn D Silver

AGENT

FIG.3
PRIOR ART

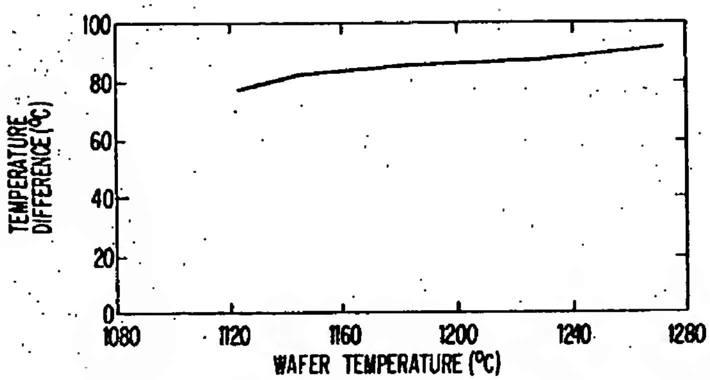



FIG.7

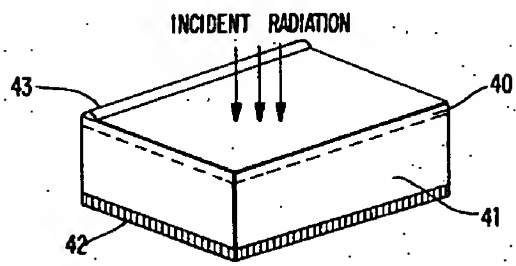
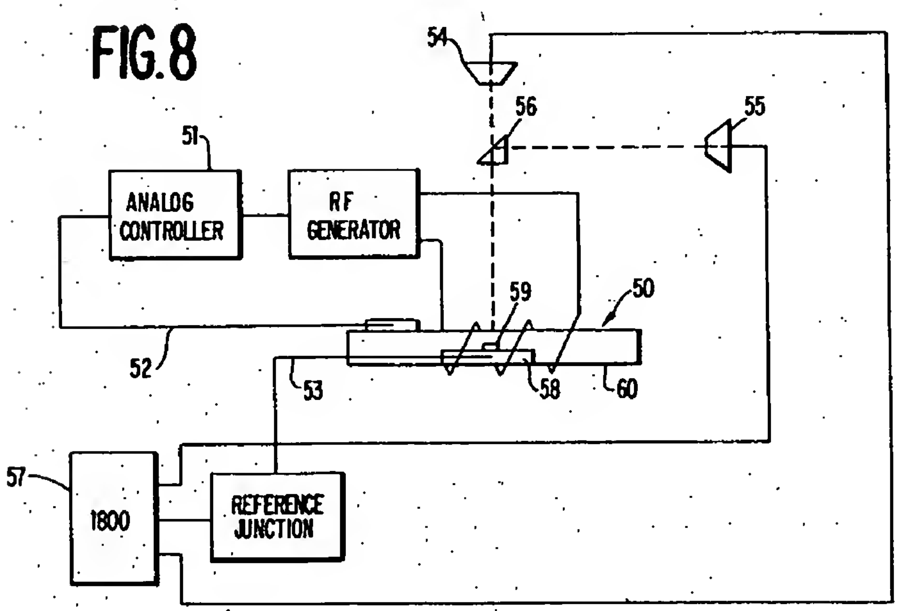



FIG.8



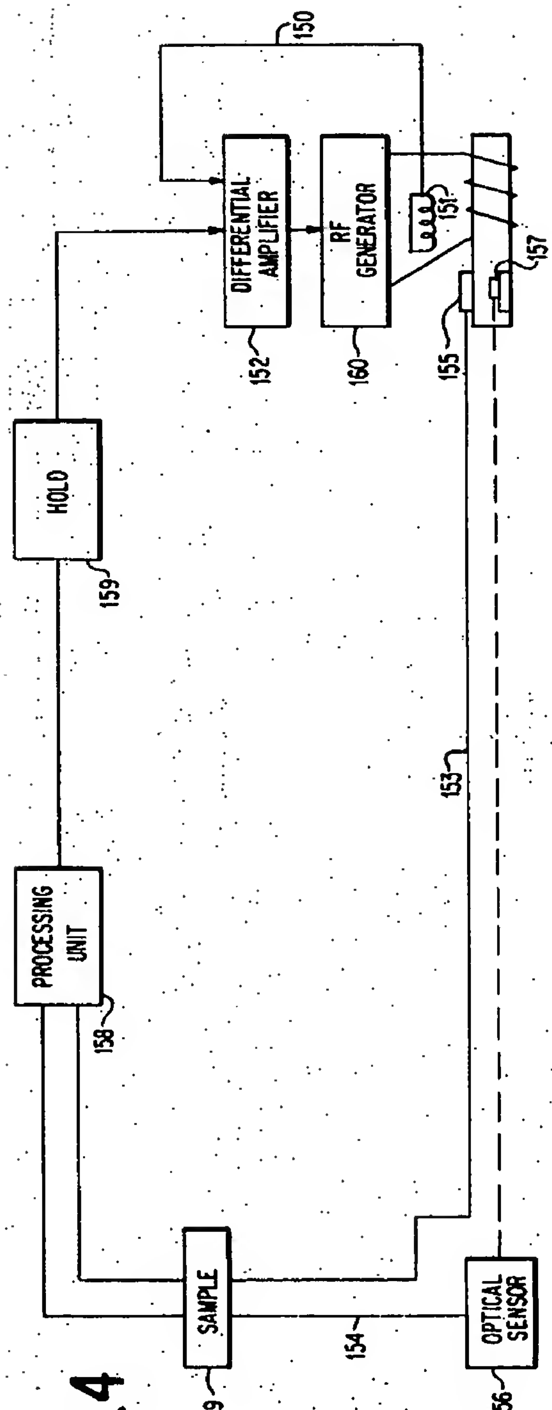

150
DIFFERENTIAL AMPLIFIER
RF GENERATOR
151
157
152
160
155
HOLD
159
153
PROCESSING UNIT
158
SAMPLE
149
154
OPTICAL SENSOR
156

FIG.4

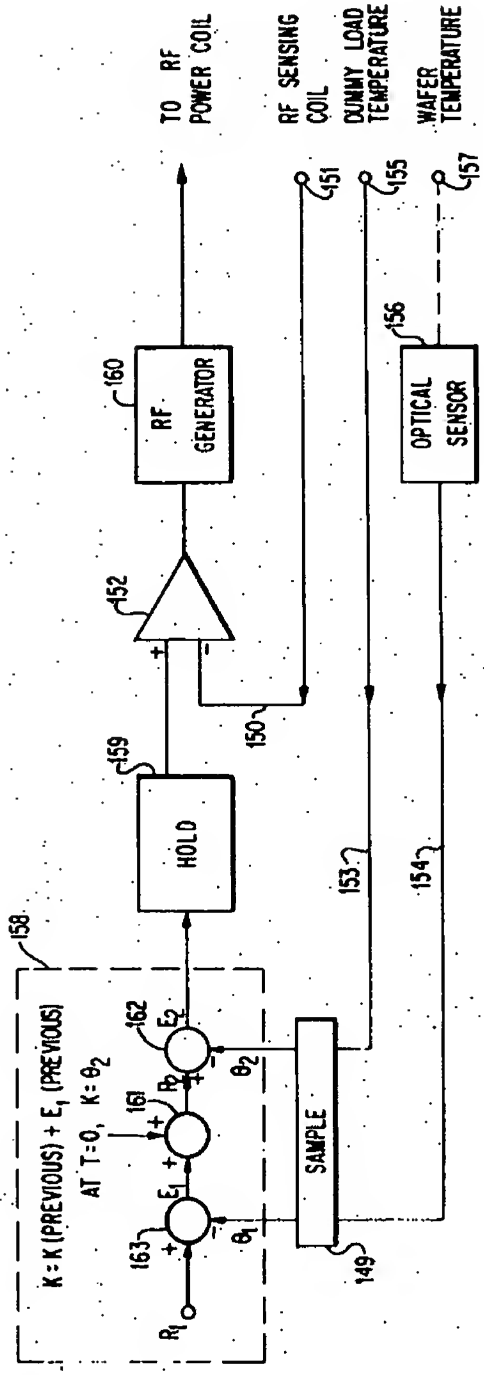

TO RF POWER COIL
RF SENSING COIL
DUMMY LOAD TEMPERATURE
WAFER TEMPERATURE
151
155
157
160
RF GENERATOR
156
OPTICAL SENSOR
152
150
159
HOLD
153
154
158
K = K (PREVIOUS) + E1 (PREVIOUS)
AT T=0, K=θ2
162
161
163
R1
E1
E2
θ1
θ2
SAMPLE
149

FIG.5

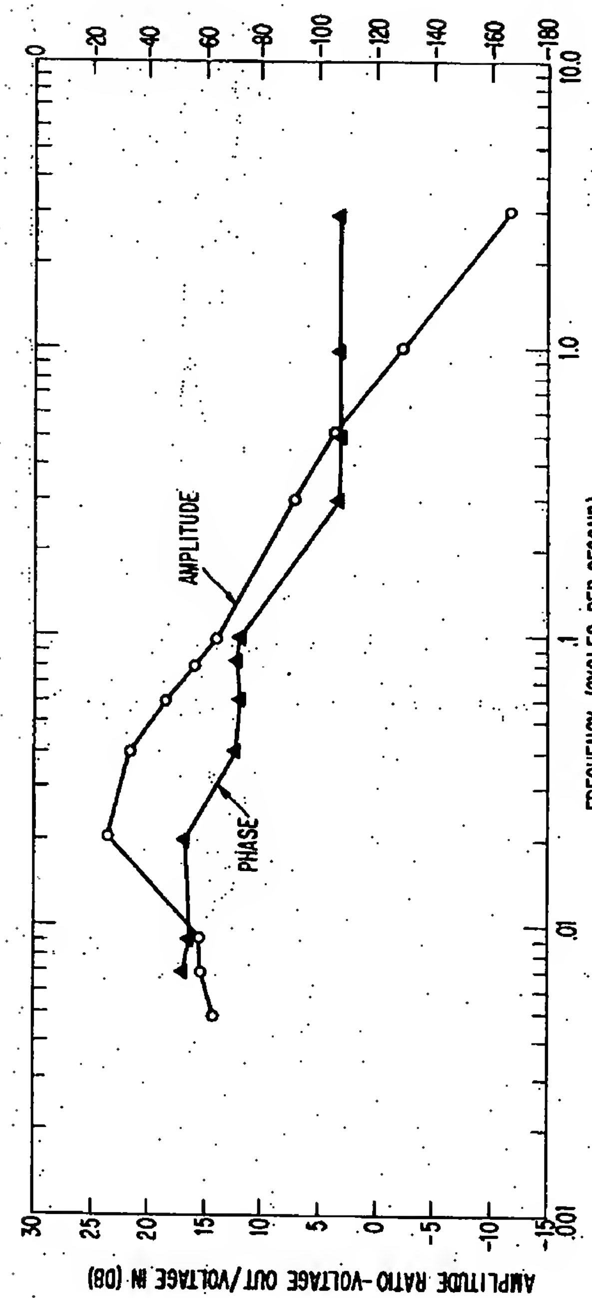

AMPLITUDE RATIO-VOLTAGE OUT/VOLTAGE IN (DB)
30
25
20
15
10
5
0
-5
-10
-15
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
.001
.01
.1
1.0
10.0
FREQUENCY (CYCLES PER SECOND)
AMPLITUDE
PHASE

FIG. 17

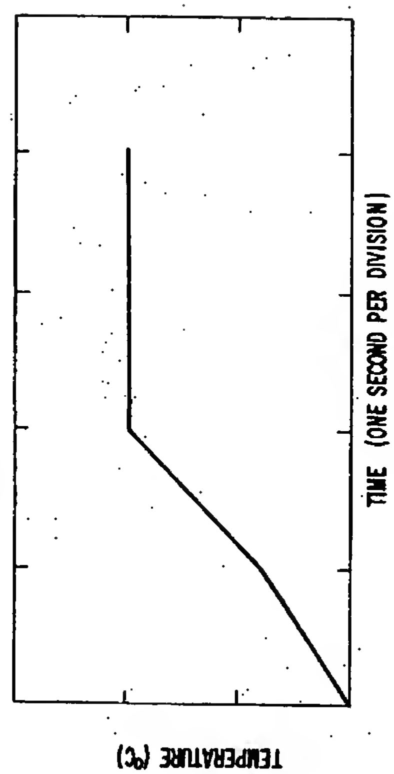

TEMPERATURE (°C)
TIME (ONE SECOND PER DIVISION)

FIG. 6

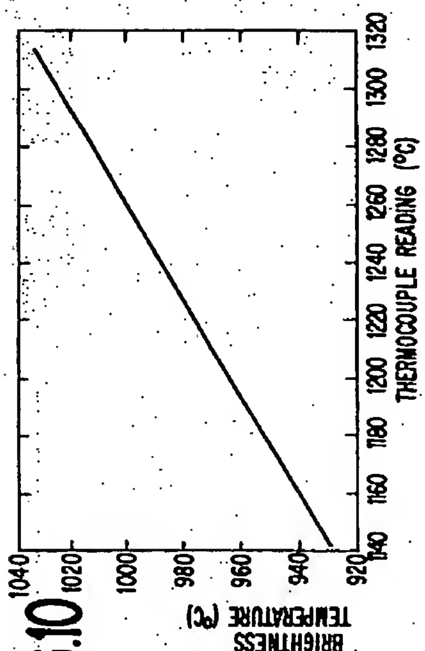



FIG.10

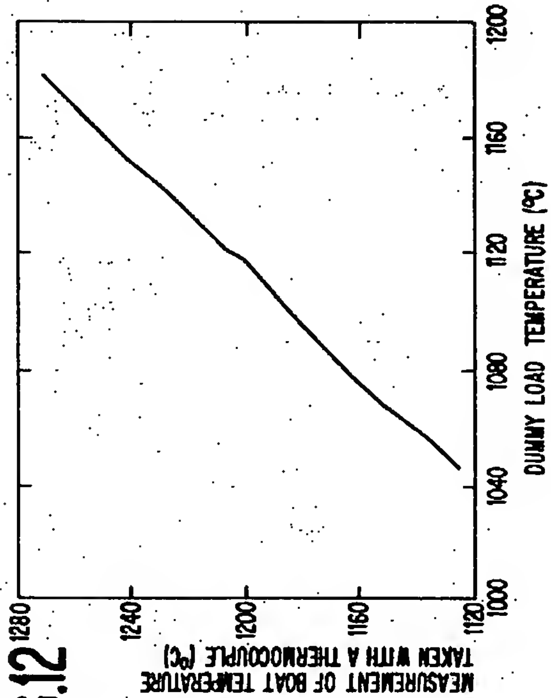



FIG.12

FIG.9

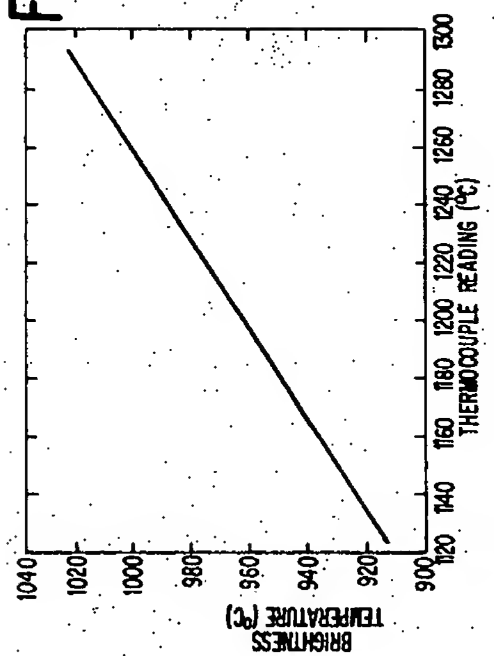
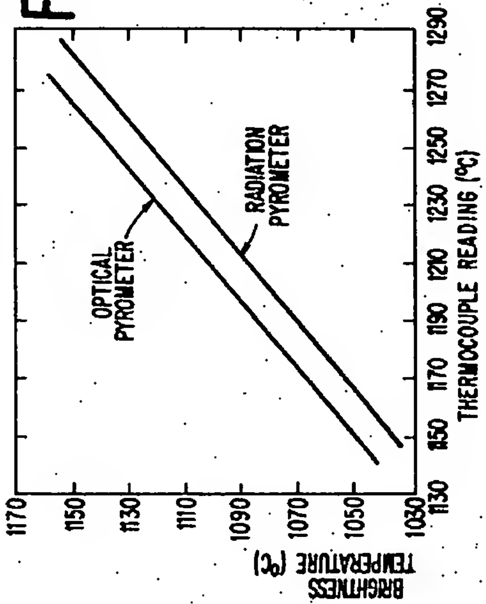



FIG.11



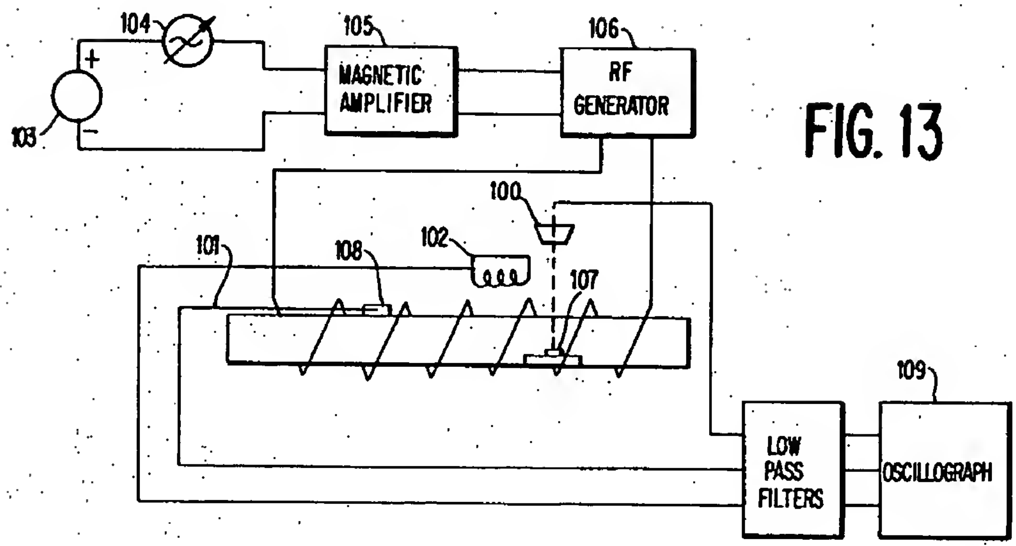

104
105
106
MAGNETIC AMPLIFIER
RF GENERATOR
103
100
101
108
102
107
109
LOW PASS FILTERS
OSCILLOGRAPH

FIG. 13

FIG. 14

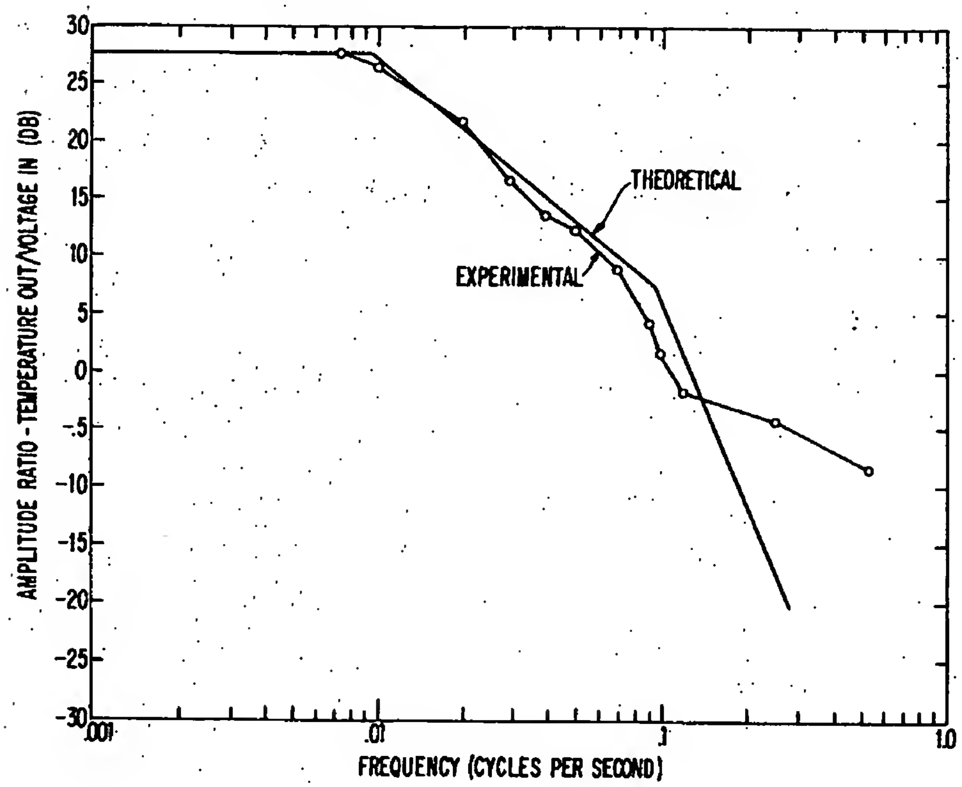

30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
.001
.01
.1
1.0
THEORETICAL
EXPERIMENTAL
AMPLITUDE RATIO - TEMPERATURE OUT/VOLTAGE IN (DB)
FREQUENCY (CYCLES PER SECOND)

FIG.15

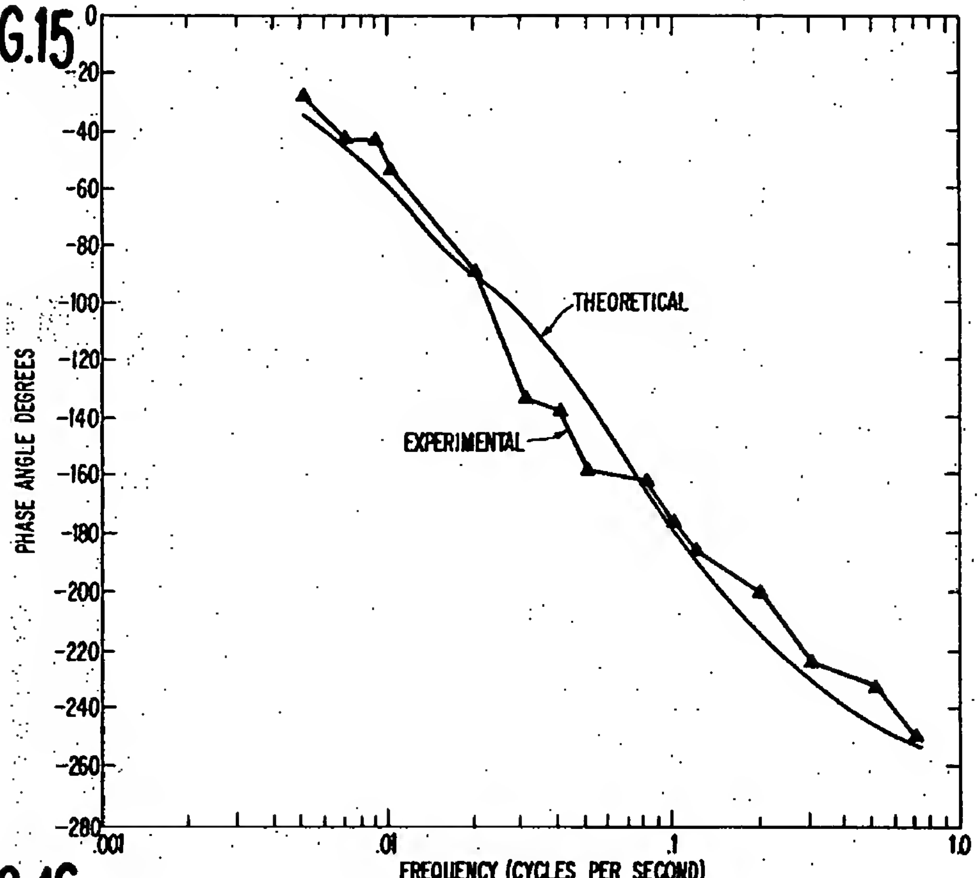
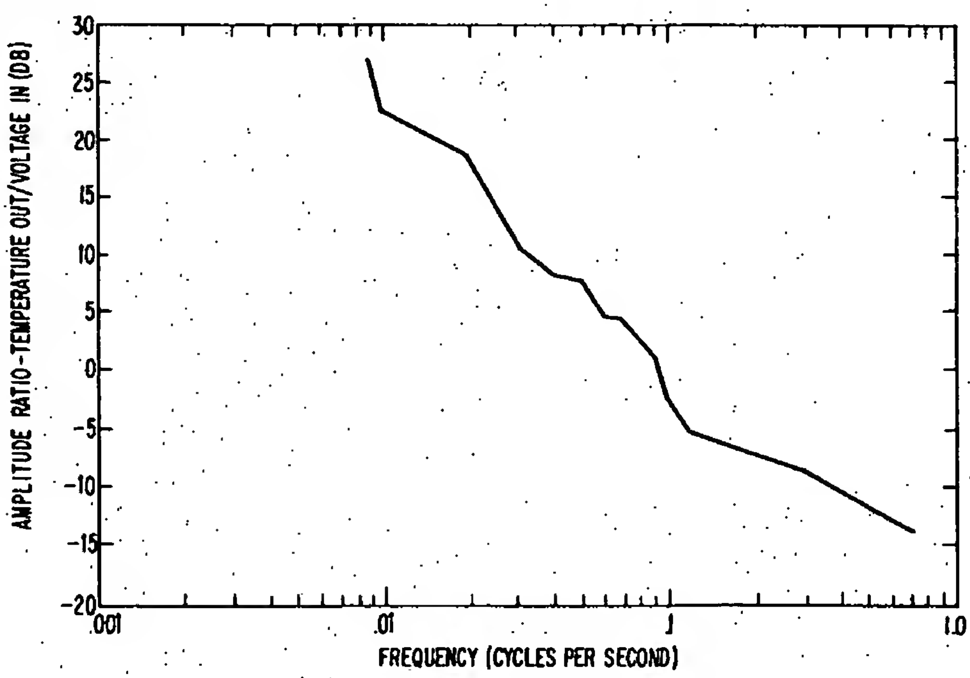

0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
-220
-240
-260
-280
PHASE ANGLE DEGREES
THEORETICAL
EXPERIMENTAL
.001
.01
.1
1.0
FREQUENCY (CYCLES PER SECOND)

FIG. 16


30
25
20
15
10
5
0
-5
-10
-15
-20
AMPLITUDE RATIO-TEMPERATURE OUT/VOLTAGE IN (DB)
.001
.01
.1
1.0
FREQUENCY (CYCLES PER SECOND)

## TEMPERATURE CONTR L SYSTEM

### FIELD OF THE INVENTION

Systems for and methods of controlling the temperature in a heating system. Such control systems and methods include sensors such as thermocouples and pyrometers, and other sensing means, as well as digital and analogue controllers for controlling heat energy input to the vessel, reactor, or object being heated.

### BACKGROUND OF THE INVENTION

Epitaxial growth is a technique in the manufacturing of semiconductor devices. The technique involves arranging, for example, silicon atoms upon a single crystal silicon substrate so that the lattice structure of the resulting layer is an exact extension of the substrate crystal structure. The basic chemical reaction that takes place during the growth process is the hydrogen reduction of silicon tetrachloride,

$1150—°C.\ SiCl_4+2H_2\ Si+4HCl$

this gas phase reaction, a gas which contains silicon atoms is passed over the substrate. Silicon atoms released from the gas phase by the reaction attach themselves to the substrate crystal structure. The elevated temperature required for the process varies from 1150° C. to 1250° C., depending on the desired growth rate. In addition to growing epitaxial layers of intrinsic silicon, it is possible to grow layers with impurity concentration, by adding doping gases such as boron, to the gas phase.

A system for growing epitaxial layers generally contains three basic parts: the reaction chamber, the feed system, and the heating source, generally an induction generator.

The reaction chamber usually consists of a long quartz tube with inlet and outlet at opposite ends, encircle by an induction coil. Silicon wafers are placed on rectangular graphite blocks, called boats, which move slowly at a constant rate through the reaction chamber. Heating is obtained indirectly by inductive heating of the boats upon which the wafers are lying.

The feed system supplies $H_2$, $SiCl_4$, and the doping gases required and controls their quantities. Automatic control of gas flow is achieved in the system by well known means, and will not be discussed further.

The induction generator (also called an RF generator) supplies, for example, 50KW output power at 6000V and 350kHz. The current in the induction coil generates a magnetic (and electric) field whose direction is parallel to the axis of the coil. The changing magnetic flux induces eddy currents in the graphite boats which, in turn, produce the heating effect. The developed heat is proportional to the RF current, its frequency, the resistivity of the material, and its permeability.

Temperature is only one of the variables affecting epitaxial growth, but it is the hardest to control. When making semiconductor devices using the epitaxial technique, it is important to keep the product characteristics uniform from wafer to wafer within a run, and from run to run. Two characteristics, film thickness and resistivity, are temperature dependent; hence, their uniformity requires precise temperature control. The function of a temperature control system is to insure temperature repeatability from run to run. When RF heating is used temperature is controlled by the power supplied to the induction coil. Temperature uniformity with respect to position in the reaction chamber, however, can only be effected manually, by varying the pitch of the induction coil.

With increasing speed of semiconductor devices, greater accuracy than in these prior systems, especially as to diffusion and growth rates, is required. While prior art systems have been sufficient for past needs, future demands for accurate device control via precise temperature control require improved temperature control systems.

Thus, it is an object of this invention to allow the improved maintenance of accurate temperature control in a reactor system.



Another object is to allow improved control of epitaxial growth of semiconductor wafers in a reactor by allowing improved temperature control.

Another object is to provide improved continuous control of reactor temperature, and thus, wafer temperature, in either a continuous flow or batch processing system.

### SUMMARY OF THE INVENTION

The method and structure of this invention utilize a closed loop system for maintaining a desired temperature in an epitaxial reactor of a continuous or batch processing line by utilizing two temperature sensors and a rapid control method.

The system in one embodiment includes a conventional RF feedback loop and two temperature feedback loops, e.g. a thermocouple loop and an optical sensor loop, all sensing the same general area. A thermocouple is mounted in a susceptor material disposed between an induction coil and a quartz reactor tube disposed in a concentric arrangement thereto. In turn, an optical sensor scans the average surface temperature of wafers mounted on a carrier (of susceptor material) traveling within and through the quartz tube.

In its broadest context, the optically sensed temperature is compared with a set point temperature to generate an error signal for correlation with the temperature sensed by the thermocouple loop which in turn generates a second error signal for correlation with the RF loop to provide a resultant signal which is employed to correct the reactor temperature. In effect, correctional factors are sequentially derived, in cascade form from the optical sensor loop, the thermocouple loop, and the RF loop.

The invention will best be understood when read in conjunction with the following drawings and general description.

### IN THE DRAWINGS

FIG. 1 shows a prior art temperature control system for epitaxial growth systems.

FIG. 2 shows a prior art parallel schematic of the RF generator of FIG. 1.

FIG. 3 shows the temperature difference between the product and the control thermocouple in a system such as that of FIG. 1.

FIG. 4 shows a block diagram of a temperature control system.

FIG. 5 shows a block diagram of temperature control loops.

FIG. 6 shows the time response of the system for a set point change of 1° C.

FIG. 7 shows the construction of a silicon cell as used in an optical sensor.

FIG. 8 shows a apparatus for calibration of optical sensors.

FIG. 9 shows the measurement of uncompensated brightness temperature using an optical pyrometer.

FIG. 10 shows the measurement of uncompensated brightness temperature using a radiation pyrometer.

FIG. 11 shows the measurement of brightness temperature compensated for attenuation in intervening media.

FIG. 12 shows the temperature difference between the boat and the dummy load in an epitaxial system.

FIG. 13 is a diagram of an apparatus for testing frequency response.

FIG. 14 shows the logarithmic amplitude ratio plot for the dummy load temperature.

FIG. 15 is a phase angle plot for the dummy load and the wafer temperature.

FIG. 16 is a logarithmic amplitude ratio plot for the wafer temperature.

FIG. 17 is a logarithmic amplitude ratio and phase angle plots for change in power output.

## GENERAL DESCRIPTION

### I. Prior Art

One prior art control system is a control unit that provides four control modes: proportional, reset, rate, and rate of approach. One such prior art control system is shown in FIGS. 1—3.

This system comprises an RF pickup coil 10, thermocouple 11, optical sensor 16, and set point adjusting means 17. The function of the RF pickup coil 10 is to sense changes in RF power and to provide for fast compensation for line voltage changes. Temperature is measured by a thermocouple 11 mounted in a stationary graphite block 12, acting as a "dummy load." This "dummy load" is located between the coil 18 and the quartz reactor tube 13. The temperature of the dummy load monitored by the thermocouple 12 is expected to vary only with a change in the magnetic field strength and is therefore proportional to the temperature of the boats 15. Since the dummy load 12 temperature and the wafer 14 temperature are known to differ, it is necessary to measure the wafer temperature off line with an optical sensor 16 such as an optical pyrometer and adjust the set point via set point adjusting means 17 to the controller to compensate for the difference in temperatures.

RF power output is regulated by the system shown in FIG. 2. The analogue controller output voltage 20 is supplied to the control winding of a magnetic amplifier 21. The magnetic amplifier 21, in conjunction with a SCR driver, is used to drive a three-phase self-saturating reactor 22 which is in series with the lines feeding the primary circuit of the plate transformer 23. The high secondary voltage is delivered through the rectifier tube to the plate of the induction heating oscillator 24. By varying the control voltage, the plate voltage and therefore the power output, may be varied.

The relation between the thermocouple reading and the product temperature for such a system, under controlled conditions, was determined by procedures described later and is plotted in FIG. 3. The difference between the product and the control thermocouple is plotted on the ordinate; the wafer temperature is plotted on the abscissa. The difference is seen to vary between 78 to 91° C. It is possible to use this relation in making a new set point. However, since a change in system variables, such as an increase in ambient temperature experienced after several runs, will influence this relation, accurate control of the wafer temperature will not result.

Thus, this prior art system attempts to regulate or control object (wafer) temperature in a reactor system by a gross temperature reading, with manual adjustments being made from time to time depending upon a manually taken optical sensor reading. This results in a large and unacceptable temperature variation. Neither such manual adjustment nor such time variable use of such adjustment is desirable in a reactor system, especially for epitaxial semiconductor wafer growth. While the RF heating system may be replaced with other heating systems, the temperature control problems above still are present.

### II. The Invention

A. Detailed Description

The temperature control system of this invention alleviates the prior art control problems by providing rapid, automatic temperature reading inputs to a data acquisition system, and by correlating such inputs in a given manner, generates an error signal for rapid and continuous heat input correction, as to the RF coil. For initial clarity, the invention will first be described in a preferred embodiment.

FIG. 4 is a block diagram of the temperature control system of the preferred embodiment of this invention. The system includes three control loops; an RF feedback loop 150; a thermocouple feedback loop 153; and an optical sensor feedback loop 154.

The function of the RF pickup loop 150 is to provide fast compensation for line voltage changes. This voltage variation affects the plate voltage to the oscillator tube, as discussed previously, and, hence, the amount of power output generated. The coil 151 generates an AC signal which is rectified and fed back. Over a small range this feedback signal is proportional to the controller output voltage. This DC signal is supplied as an input to differential amplifier 152, which generates an error voltage proportional to the difference between the controller output voltage and the feedback signal.

The thermocouple loop 153 via the thermocouple placed in the dummy block 155, and the optical sensor loop 154 via an optical sensor such as a radiation pyrometer 156 focused upon the wafer 157 provide a voltage output that is proportional to the temperature sensed. These signals are inputs to a sampling means 149, which samples the incoming signals on a time basis, discussed later. The output from sampling means 149 is then input to a processing means 158, which processes the input signal in a manner described below in conjunction with FIG. 5, and inputs a resultant error signal to hold means 159, from which a final signal is input to the differential amplifier 152, to control power output of the RF heating system via control of the RF generator 160.

This processing unit may be, for example, an IBM 1800 Data Acquisition System, where incoming signals are filtered, multiplexed, amplified, converted to digital form, processed, reconverted to analogue form, sampled, and fed back to the differential amplifier.

FIG. 5 is a block diagram of the temperature control loops, 153 and 154, input to sampling means 149 and then processed in processing unit 158, then input to hold means 159 which holds the signal for a given time interval related to the sampling time, to allow a continuous signal output to be input into differential amplifier 152, for control of the RF generator 160. WITHIN FIG. 5 is shown part of the function of processing means 158, wherein the desired error signal $E_2$ is generated, and then fed into hold means 159.

Thus, briefly, a thermocouple sensing means is located adjacent to the reactor to sense a gross temperature related to the internal temperature of the reactor, and generates a voltage or signal related to the temperature sensed. Similarly, optical sensing means is focused upon the object to be heated within the reactor, generating a voltage or signal related to the temperature of the object upon which it is focused. These sensing means are related to the overall structure as shown above, and in operation coact as shown below.

B. Operation

In operation, a first set point signal $R_1$ is generated, said signal related to the temperature at which it is desired to heat the object being heated, such as the semiconductor wafer. This first set point signal is then compared in comparing means 163 with the optically-sensed voltage $\Theta_1$, from the optical sensor loop 154, the difference between the first set point voltage $R_1$ and the optically-sensed voltage $\Theta_1$ constituting a first error voltage $E_1$.

Next, a $k$ factor is generated, comprising the sum of the prior occurring $K$ factor and the prior occurring first error voltage $E_1$, the initial $K$ factor at time equal to zero being made equal to the thermocouple sensed signal $73_2$ at time equal to zero. In second comparing means 161, the first error signal $E_1$ and the $K$ factor are added, the sum constituting a second set point signal $R_2$. Third comparing means 162 compares second set point signal $R_2$ with the thermocouple sensed signal $\Theta_2$, the difference constituting a second error signal $E_2$. This is a desired error signal. This error signal is then input to hold means 159 whose function is described later.

$\Theta_2$ represents the temperature of dummy load 155 that is located near the quartz tube of the reactor. Its temperature is stable, depending mainly on the magnetic field strength, but it does not reflect the temperature of the product accurately.

$\Theta_1$ reflects the wafer temperature measured accurately with a radiation pyrometer. Since the product may be moving from one end of the furnace to the other, this reading is not always

available, i.e., at times the sensor will not be focused on the wafer. Therefore, this loop is sampled much less frequently than the thermocouple sensing loop **153**.

The optically sensed temperature is first corrected using a predetermined emissivity value, discussed later. As stated, this optically sensed temperature is compared with the set point temperature $R_1$ that is generated to the processing unit. The wafer and the dummy load are at different temperatures. Hence, in order to apply the resultant error term $E_1$ as a set point to the thermocouple control loop, it is necessary to know the relationship between these two temperatures. In general, this relationship will depend on some known and some unknown independent factors such as gas flow rate, boat speed, and reactor heatup. This relationship is determined on line. $E_1$ is summed with a constant error term. This error term is updated based on optical samplings of the wafer temperature using the following equation:

$$k\,(\text{NEW}) = k\,(\text{PREVIOUS}) + E_1\,(\text{PREVIOUS}) \qquad (1)$$

The resultant error term is the set point to the thermocouple controlled loop **153**.

The complementary relationship between the dummy load temperature and the optically sensed temperature is best illustrated with an example. Referring to FIG. 5 assume:

$R_1 = 1200°$ C. is the set point
at time $= t$ assume the following readings
$\Theta_1 = 1180°$ C.
$\Theta_2 = 1098°$ C.
$E_1(t_0) = R_1(t) - \Theta_1(t_0) = 1200° - ° = 20°$ C.
Initially $k$ is taken as $\Theta_2$.
$R_2 = E_1(t) + k(r_0) = 20° + 1098° = 1118°$ C.
$E_2 = R_2(t) - \Theta_2(t_0) = 20°$ C.

As expected, the temperature drop seen by the optical sensor loop is also seen by the other loop.

at time $= t + T$ assume the following:
$\Theta_1 = 1205°$ C.
$\Theta_2 = 1119°$ C.
$E_1(t_0+T) = R_1 - \Theta_1(t_0+T) = -5°$ C.
$k(t+T) = k(t_0) + E_1(t_0) = 1118°$ C.
$R_2(t_0+T) = E_1(t+T) + k(t_0 T) = -5° + 1118° = 1113°$ C.
$E_2 = R_2(t+T) - \Theta_2(t_0+T) = -6°$ C.

This error correction continues until $E_1$ equals zero at which time $R_2$ remains constant.

This error signal $E_2$ is now input to hold means **159**. It is thus necessary to consider loop response times, to determine sample times for sampling means **149** and frequency of signal output from the hold means **159** to differential amplifier **152**. The purpose of this is so that the sample means can input signals to the processing unit that are meaningful, as a time response is associated with the temperature sensors to reflect a change in temperature, such change being evident as a change in signal voltage for such sensors. The hold means will hold the resultant error signal for this time interval, until a new signal is generated.

It is assumed that the response of the RF pickup loop **150** is about 10 times faster than the temperature response. This assumption is verified by comparing Bode plots for the RF power and for the dummy load temperature. Therefore, only of concern is the forward path of the Rf loop transfer unction, which is included in the dummy load transfer function. Similarly, since the wafer temperature is sampled at a much slower rate than the dummy load temperature, variations in it are treated as set point changes.

From the Bode plots in FIGS. 14 and 15, discussed later, obtain the following transfer function:

$$G(s) = \frac{A}{(s+.0095)(s+.095)^2} \qquad (2)$$

where

$$A = 24.4\,|(j\omega+.0095)(j\omega+.095)^2|_{\omega=.007} = 2.62\times10^{-3} \qquad (3)$$

combining $G(s)$ with the zero order hold;

$$\frac{\theta}{U} = \left[\frac{(1-e^{-st})}{s}\,\frac{A}{(s+.0095)(s+.095)^2}\right] \qquad (4)$$

proceed to expand in partial fractions and obtain:

$$\frac{\theta}{U} = (1-e^{-st})\left[\frac{30.7}{s} - \frac{38.3}{(s+.0095)} + \frac{7.29}{(s+.095)} + \frac{.325}{(s+.095)^2}\right] \qquad (5)$$

In a digital control system, the system must be described in sampled data form. Before converting to $z$ transform notation, a sampling period must be picked. The sampling theorem states that, for a band limited signal, it is theoretically possible to recover completely the signal from its sampled form if the bandwidth of the former is limited to one-half the sampling frequency. Practical considerations require a sampling frequency of at least five times the bandwidth.

The bandwidth of the dummy load temperature response is taken as the crossover frequency of the logarithmic amplitude ratio plot.

FIG. 14 shows that the crossover frequency for the dummy load temperature response equals 0.11 cycles/second. Therefore, a sampling frequency of 1 cycle/second is reasonably higher. Hence the sampling period T is taken as 1 sec. higher.

Now apply the $z$ transform rules and obtain:

$$\frac{\theta}{U}(s) = (1-z^{-1})\,\frac{30.7}{1-z^{-1}} - \frac{38.3}{1-.99055z^{-1}} + \frac{7.29}{1-.9093z^{-1}} + \frac{.293z^{-1}}{(1-.9093z^{-1})^2} \qquad (6)$$

after simplifications

$$\frac{\theta}{U}(z) = G(z) = \frac{.31(-1+1.91z^{-1}-.4323z^{-2}-8.04z^{-3})}{(1-.99055z^{-1})(1-.9093z^{-1})^2} \qquad (7)$$

factoring the numerator

$$G(z) = \frac{.31(1+1.475z^{-1})(-1+3.385z^{-1}-5.432z^{-2})}{(1-.99055z^{-1})(1-.9093z^{-1})^2}$$

The transfer function contains a zero outside the unit circle at $-1.475$, and poles at $=.99055$ and $.9093$, the latter being a double pole.

To satisfy the requirement for ripple free, finite settling time response the prototype response function $K(z)$ must contain the zero of $G(z)$.

$$K(z) = (1+1.475z^{-1})(a_1z^{-1}) \qquad (8)$$

$$1-K(z) = (1-z^{-1})(1+b_1z^{1}) \qquad (9)$$

in equating terms, obtain two simultaneous relations:

$$a_1 = 1-b_1$$
$$1.475a_1 = b_1 \qquad (10)$$

$$a_1 = .404$$
$$b_1 = .596$$

$$K(z) = .404z^{-1} + .596z^{-2} \qquad (11)$$

The time response of the system for a step input is plotted in FIG. 6.

The pulse transfer function is computed now as:

$$D(z) = \frac{1}{G(z)}\,\frac{K(z)}{1-K(z)} \qquad (12)$$

$$D(z) = \frac{.404z^{-1}-.539z^{-2}-.61z^{-3}+1.246z^{-4}-.493z^{-5}}{-.31+.716z^{-1}-.188z^{-2}-2.79z^{-3}+1.08z^{-4}+1.49z^{-5}} \qquad (13)$$

This response is implemented by storing the last five samples of the output.

Thus, the error signal $E_2$ is input to sampling means **149**, which then utilizes a sampling period of 1 second. The output after processing is then input to the hold means, and then input to the differential amplifier **152**, for ultimate control of the heating system via RF generator **160**.

Thus, this invention automatically samples data from at least two functionally different points via thermocouple and optical sensors, utilizing a sampling period and error correction method designed to achieve accurate controllable temperature control in a reactor system. Manual reading errors and uncertain times of correction are eliminated, and a

superior single correction—a final error signal—generated to correct and maintain the entire system.

While the invention has been described above, in a specific embodiment for clarity, it is important to understand the considerations and factors that allow the invention disclosed to function in the manner disclosed. This requires an understanding of (1) temperature measuring techniques and (2) direct process control.

### 1. Temperature Measuring Techniques

The well-known technique of measuring surface temperature by sensing thermal radiation is becoming increasingly popular in semiconductor manufacturing today. Hamlin in his article "Multiple IR Heads for Complete Control of Temperature and Growth Thickness in Epitaxial Reactors", IEEE International Convention Record, 1967, Part 14, pp. 52—57, describes a system (not shown) of three infrared sensors measuring the temperature of three reactor zones and feeding it to an analogue controller. This technique has the following distinct advantages over other techniques of temperature measurement: (1) Contact with the surface is not necessary, hence this technique can be use in cases where contact measurement is not feasible. (2) It is the only technique available in corrosive or otherwise hostile environments. (3) The technique has good sensitivity to very small temperature changes over fixed or moving objects. (4) It has very fast response in most cases because of the absence of thermal mass which limits the speed of response in thermal detectors.

Thermal radiation detectors thus have some clearly desirable characteristics.

Thermal radiation detectors are divided into two general categories: optical pyrometers and radiation pyrometers.

The measurement of temperature utilizing optical pyrometry is based on the fact that the spectral radiant intensity from an incandescent body is a function of temperature. If the body is black (radiating all the energy it absorbs), the spectral radiant intensity is related to the temperature according to Planck's radiation equation:

$$N_{b\lambda}=\frac{C_1\lambda^{-5}/\pi}{e^{C_2/\lambda T}-1} \quad \ldots \qquad (14)$$

$N_b\lambda$ the spectral radiant intensity at the wavelength $\lambda$ of a black body at a thermodynamic temperature $T$; $C_1$ and $C_2$ are the first and second radiation constants. Thus, if $N_b\lambda$ and the other parameters in equation (14) are known, it is possible to determine the temperature. Absolute measurements of radiation, however, are very difficult to take. Therefore, $N_b\lambda$ is generally measured relative to some standard spectral radiant intensity. This measurement is done by imaging the source whose temperature is to be determined onto the filament of the pyrometer lamp. Then the lamp intensity is varied until the filament disappears into the background of the source. A band-pass filter is used to limit the instrument bandwidth. The matching is done manually using the eye as a detector, or automatically, using a photomultiplier tube. The wavelength of the pyrometer is fixed according to the temperature range over which it will be used. Because objects at higher temperatures radiate at shorter wavelengths, pyrometers for temperatures above 1000° C operate in the visible spectrum. Optical pyrometers are accurate, and are often used to calibrate other sensors.

An optical pyrometer is used in the calibration procedure of this invention, and will be described later. Its readings are used as a reference to check the stability of the radiation pyrometer.

A radiation pyrometer is a device that collects thermal radiation from a target and then converts the thermal energy into an electrical signal. Only one type of radiation pyrometers is here described, the silicon cell, which is used to measure the wafer temperature. It is recognized that other types may be used. The silicon cell is a solid state device that generates an electric current when illuminated with near infrared radiation. The structure of a silicon solar cell is shown in FIG. 7. A thin layer of $p$—type silicon 40 is laid on a thicker layer of $n$—type silicon 41. The negative contact 42 is deposited on the back



surface of the silicon, while a metallized strip 43 on the top surface forms the positive contact.

If the contacts are electrically connected through a suitable resistive load, a current flows in the circuit without the use of an external source. The current is proportional to the intensity of the incident radiation and, hence, to the temperature of interest.

Optical pyrometers and radiation pyrometers infer temperature by measuring radiated energy. Since radiated energy and temperature are related according to Planck's radiation law, the radiation pyrometer reading will be correct only for the case of a black body. Most real objects, however, do not radiate all the energy that they absorb; a part gets transmitted or reflected. Hence, most real bodies are not black bodies. Emissivity expresses the ratio of the energy radiated by a real body under a given set of conditions to the energy radiated by a black body under the same conditions. Emissivity values vary between 0 and 1, where unity is the emissivity of a black body. An uncalibrated sensor measuring a real body will therefore indicate a lower temperature than the true temperature. Emissivity is dependent on the material, surface condition, temperature and wavelength of the measuring instrument. Since the emissivity of, for example, silicon wafers varies widely, it is important to calibrate the sensors so that the true temperature may be known.

An empirical calibration method is here employed.

The purpose of this method is the following:

1. To obtain the temperature difference that might be expected between the temperature of the "dummy load" and the temperature of the wafer under fixed conditions.
2. To measure the emissivity of the wafer in the applicable temperature range.

The measurements are taken for the two types of optical sensors, however, the radiation pyrometer is of primary concern. The optical pyrometer is used to compare measurements and to evaluate the repeatability of the radiation pyrometer.

FIG. 8 shows a block diagram of the apparatus used in this calibration.

Thus, the apparatus includes epitaxial reactor 50 whose temperature is controlled by means of analogue controller 51 and a control thermocouple 52 via the RF generator. It further includes a measuring system consisting of a measurement thermocouple 53 embedded in a carbon boat 58 and the optical sensors, radiation pyrometer 54, prism 56, and optical pyrometer 55. The recording system consists of a plata aquisition system, such as an IBM 1800 Computer 57, program controlled to sample the points and list the results.

The black body used for calibration consists of carbon block 50 with a hole paralleling its long axis. The measuring thermocouple 53 is inserted in this hole. The wafer 59 is placed on the block in a double notch arrangement for better temperature uniformity, and the center of the wafer is aligned with the thermocouple tip. Because of the close proximity of the thermocouple to the target area of the wafer, the thermocouple measures the thermodynamic temperature of the wafer.

The emissivity of the wafer for a given temperature and wavelength is computed using the following formula:

$$\epsilon=EXP\left\{\frac{C}{\lambda}\left(\frac{1}{T_T}-\frac{1}{T_B}\right)\right\} \qquad (15)$$

where:

$\epsilon$ = spectral normal emissivity
$\lambda$ = effective wavelength of the sensors
= 0.6450 microns for the optical pyrometer
= 0.9 microns for the radiation pyrometer
$T_T$ = Thermodynamic temperature
$T_B$ = Brightness temperature (temperature sensed by the pyrometer)
$C$ = a constant, 14380.0 micron °K

In this system there is, beside emissivity, another factor that affects $T_B$. The sensors are sighted through the quartz tube 60 and there is some loss of thermal energy in the wall. There are also losses in the prism 56. In order to obtain $T_B$ this loss has to be accounted for. This is done by taking two measurements:

First, the sensors are sighted on the wafer 59. Readings of the sensors ($T_b'$) and of the measuring thermocouple 53, are taken.

Second, the sensors are sighted on an opening in the carbon block 58 (emissivity≈1) in the near proximity of the thermocouple 53 tip. Again readings of the sensors 54, 55 and of the measuring thermocouple 53 are taken. The temperature difference due to losses in the quartz and prism wall $\alpha T$ is then computed and added to $T_B'$.

$T_B = T_B' + \alpha T$

Measurements are taken over a range of 165° C at 10° C intervals. The temperature is changed by varying the set point for the control thermocouple 52. All three sensors 53, 54, 55 provide voltage inputs to the 1800 system and are scanned simultaneously. The readings are averaged by the computer with an average taken every 10 readings (4 sec.). Temperature stability of 1° C is insured before taking a calibration point.

FIGS. 9—11 show the comparison of uncompensated and compensated temperature readings on this calibration.

FIG. 9 and FIG. 10 plot the uncompensated brightness temperature for the optical pyrometer and for the radiation pyrometer respectively. FIG. 11 is the plot of the brightness temperature compensated for losses in the prism and quartz wall in the case of the radiation pyrometer.

The plot shows that the radiation pyrometer readings are lower by a constant amount from the optical pyrometer readings.

Note that in FIGS. 9 & 10 the two scales are different. If they are made equal, the two plots show approximately the same values. The apparent discrepancy between these plots and FIG. 11 is explained by the fact that in the case of the optical pyrometer, there is a reduction in radiant intensity due to losses in both the prism and the quartz wall. In the case of the radiation pyrometer, here are only losses in the quartz wall. The additional losses in the optical pyrometer measurements made the readings appear identical. In FIG. 11, where the readings are compensated for losses, the difference between the plotted points is evident.

The emissivity values are computed using formula (15) and are based on a linear curve fitting. The values are as follows:

For the Optical Pyrometer

$\epsilon \approx 0.30 \quad 1140 \leqq T \leqq 1280°$ C.

For the Radiation Pyrometer

$\epsilon \approx 0.38 \quad 1140 \leqq T \leqq 1280°$ C.

The emissivity correction is applied to the wafer measurement as described in the section on the control system, discussed later.

FIG. 12 shows the relation between the control thermocouple reading and the product temperature as monitorized with the measurement thermocouple under controlled conditions.

## 2. Direct Control of Process

Experimental frequency response data is needed for design of the parameters employed in the sampling means. This data is used to determine the loop transfer functions, discussed previously in connection with FIG. 5.

a. Theoretical

The determination of a transfer function when a forcing function is applied at the input, and a response is measured at the output is a well-known way of arriving at the dynamic characteristics of a linear time-invariant system. When initial conditions may be ignored, the relationship between the input forcing function and the output response function is given by:

$$\text{Transfer Function} = \frac{\text{Output Response}}{\text{Forcing Function}}$$

A straightforward way of testing system dynamics is to apply a sinusoidally varying input at a given frequency and observing the steady state amplitude and phase of the response. This procedure is then repeated for different frequencies. Normally, it will be required to cover at least two decades of frequency. The input and output quantities are recorded simultaneously. The test is sustained long enough to permit the initial transients to disappear, leaving only the steady state conditions. Several complete cycles are generally required before the transient characteristics of the output signals become negligible.



Certain assumptions are made in determining these frequency response relationships.

Assume that the behavior of the system can be described by an $n^{th}$ order linear differential equation with constant coefficients. Designate as $x(t)$ the input to the system, or the independent variable and $y(t)$ y(t) the output of the system, or the dependent variable. Further assume zero initial conditions of $y(t)$ and $4(t)$ and their first $(n-1)$ and $(m-1)$ derivatives, respectively:

$$a_0 y(t) + a_1 \frac{dy(t)}{dt} + a_2 \frac{d^2y(t)}{dt^2} + \cdots a_n \frac{d^n y(t)}{dt^n}$$
$$= b_0 x(t) + b_1 \frac{dx(t)}{dt} + b_2 \frac{d^2x(t)}{dt^2} + \cdots b_m \frac{d^m x(t)}{dt^m};\ n \geq m \quad (16)$$

$$y(0) = y'(0) = \ldots y^{n-1}(O) = O \quad (17)$$

$$x(0) = x'(0) = \ldots x^{m-1}(O) = O \quad (18)$$

Now apply a sinusoidal excitation at the input:

$$x(t) = a \sin \omega t \quad (19)$$

and solve for the response $y(t)$.

Rewriting (16) in summation notation:

$$\sum_0^n a_k \frac{d^k y(t)}{dt^k} = \sum_0^m b_k \frac{d^k X(t)}{dt^k} \quad (20)$$

and taking the Laplace transform of (8),

$$\left(\sum_0^n a_k s^k\right) Y(s) = \left(\sum_0^m b_k s^k\right) X(s) \quad (21)$$

Let

$$N(s) = \sum_0^m b_k s^k \quad (22)$$

$$D(s) = \sum_0^n a_k s^k \quad (23)$$

$$Y(s) = \frac{N(s)}{D(s)} \frac{A_\omega}{s^2+\omega^2} \quad (24)$$

Let

$$G(s) = \frac{N(s)}{D(s)} \quad (25)$$

The steady state response of $Y(s)$ comes from the pure imaginary poles of the driving function or the pure imaginary poles of $G(s)$.

Assume that the real part of the poles of $G(s)$ are negative, therefore $G(s)$ can not have pure imaginary poles. Hence, only the poles of the driving function contribute to the steady state response.

It follows that the steady state response of the system is:

$$y_{ss} = \sum \text{ residues of } G(s)\frac{A\omega e^{st}}{s^2+\omega^2} = G(s)\frac{A\omega e^{st}}{(s+j\omega)}\bigg|_{s=j\omega}$$

at $s = j\omega;\ s = -j\omega$

$$+ G(s)\frac{A\omega e^{st}}{(s-j\omega)}\bigg|_{s=-j\omega} = \frac{A}{2j} G(j\omega)[e^{j\omega t} - e^{-j\omega t}] \quad (26)$$

expressing $G(j\omega)$ as a product of magnitude and phase

$$G(j\omega) = \left|G(j\omega)\right| e^{j\Theta(\omega)} \quad (27)$$

$$G(-j\omega) = \left|G(j\omega)\right| e^{-j\Theta(\omega)} \quad (28)$$

the following is obtained,

$$y_{ss}(t) = A\left|G(j\omega)\right| \sin[\omega t - \Theta(\omega)] \quad (29)$$

The steady state response data is usually shown as Bode plots, one for the amplitude ratio and one for the phase angle.

Theoretically, it is not necessary to use sinusoidal forcing to arrive at the system response. The same information can be

obtained by applying an arbitrary pulse-like disturbance to the input. For a linear system and arbitrary input $x(t)$, the technique is to obtain the Fourier transform of the independent and dependent variables.

The transfer function is obtained by dividing the dependent variable Fourier transform by that of the independent variable:

$$\frac{\int_0^{T_y} y(t)e^{-j\omega t}dt}{\int_0^{T_x} x(t)e^{-j\omega t}dt}=\frac{Y(j\omega)e^{j\phi_1(\omega)}}{X(j\omega)e^{j\phi_2(\omega)}}=\frac{1}{G(j\omega)} \quad (30)$$

Since both $y(t)$ and $x(t)$ are pulses and go to zero for finite time, they are Fourier transformable and the integrals may be evaluated for each value of $\omega$. This is done using numerical integration.

The pulse method is especially attractive for testing chemical processes since it can be conducted during normal production runs and can be implemented with readily available equipment.

b. Operation

A block diagram of apparatus for these measurements is shown in FIG. 13, showing radiation pyrometer 100, thermocouple 101, pickup coil 102, DC supply 103, signal generator 104, and related equipment.

The frequency response measurements thus taken help determine a suitable sampling rate, and obtain the open loop transfer function. This transfer function is used in the sampling procedures.

In operation, a sinusoidal disturbance is introduced at the input to the system by varying the control voltage to the magnetic amplifier 105. The response of three input variables is monitored. The variables are: the wafer 107 temperature, the dummy block 108 temperature, and the variation in power output sensed by the pickup coil 102.

The control voltage is varied by means of signal generator 104. The readings are taken at a typical operating range of the system, about 1150° C. First, the system is allowed to stabilize at that temperature and then the disturbance is introduced. The sine wave in this case is riding an 18V DC signal. The sine amplitude is 2V initially. In order to excite the system sufficiently at higher frequencies, it is necessary to increase the amplitude gradually up to 8V maximum. The system is allowed to reach steady state at each frequency.

The various variables are monitored by a multichannel oscillograph 109. Its fast response does not delay the output signals. Also, because of their fast responses, the radiation pyrometer 100 (1 ms) and the thermocouple 101 do not affect the measurements.

The results are shown graphically in FIGS. 14—16, which Bode plots were used in determining the sampling period discussed previously in connection with FIG. 5.

The frequency response of the three output variables is shown graphically as Bode plots. The logarithmic amplitude ratio plot for the dummy load temperature is shown in FIG. 14. The transfer function is approximated by a third order system with a single pole at 0.0095 cycles/sec., and a double pole at 0.095 cycles/sec. The theoretical and experimental transfer functions are in good agreement except at above 0.12 cycles/sec. At this frequency range it is necessary to apply large amplitudes of the input disturbance in order to excite the system sufficiently. The system, under this condition, is probably no longer linear. The phase angle plot for both the dummy load temperature and for the wafer temperature is given in FIG. 15.

The logarithmic amplitude ratio plot for the wafer temperature is shown in FIG. 16. The phase plot is not shown as this was almost identical to the phase plot shown in FIG. 15. As expected, the amplitude ratio plots are in agreement except that the wafer temperature has a lower DC gain. This is expected since the uncompensated reading of the wafer temperature was lower than the dummy load temperature. FIG. 17 is the logarithmic amplitude ratio and the phase angle for the RF power output. The band-pass is about 10 times higher than the temperature band-pass.

In the above experimental determinations, another correctional factor was necessary to nontheoretically perfect system conditions.

Some of the energy that is supplied to the induction heating escapes from the process and interferes with the operation of the IBM 1800 computer and other equipment that is present in the same room. The RF interference causes erroneous readings of the analogue signals applied to the 1800 system. The interference also causes the oscillograph readings to become noisy. Therefore, this noise problem must be solved before the work described above can be carried out.

Shielding the RF coil with an aluminum case is effective in greatly reducing the effect of the interference on the 1800 readings and practically eliminating the effect on the oscillograph readings. In addition to the shielding, low pass filters are installed on all the signal lines that are brought from the epitaxial system to the 1800. This reduces the noise to a tolerable level.

The following is a brief summary of these considerations and the reasons for them.

## GENERAL SUMMARY

The increasing complexity and density of integrated circuits require close tolerances of the product specifications. Since temperature has a significant effect on the product characteristics in the epitaxial growth system, close temperature control is required to insure product uniformity. In order to improve the level of a control system it is necessary to measure the deposition temperature more accurately. The technique of radiation pyrometry provides a solution to this difficult problem. The transfer function of the system is determined experimentally from its frequency response. This method is preferred over the method of pulse testing because the desired test response is readily distinguished from other responses present in the system, and because it is believed to lead to a more accurate model of the system.

The advantage of this system compared to other systems is the more accurate control of the deposition temperature. However, another advantage is due to the use of Direct Process Control (DPC).

With a DPC system, control calculations such as the emissivity corrections are readily implemented in a computer which includes the processing means and sample and hold means. Also with a DPC system, individual hardware elements are replaced with the time shared components of the control computer. In a digital system, the measurement of analogue signals from the transducers is accomplished via multiplexed components in the analogue to digital converter section. Individual set point stations for each controlled variable are replaced by keyboards and switches that permit the operator to manually enter set points and other data for individual control loops. By utilizing multiplexed components, a data acquisition system such as the IBM 1800 system can sample and control about 100 loops per second with one analogue to digital converter.

The software required to implement the control algorithm is a part of a larger DPC program that is utilized to control temperature, flow and other process variables. Given the prior information and desired result, a programmer skilled in the art can program the computer. Thus, heating means other than RF may be used, such as electrical resistance or gas, for example. The important quantities to be measured or used is the gross temperature of the reactor and the surface temperature of the reactor and the surface temperature of the object being heated, such as the semiconductor wafer, or for gas phase reactions, an area of the reactor itself. The means for obtaining the error signals need not be as complex as an IBM 1800 system. The method disclosed is applicable beyond epitaxial growth processes, but to general heating systems and problems.

What is important is that signals representative of the temperatures involved be generated so that error signals may be generated for correcting the heat input to the reactor. The heat energy input controllers, of course, may be responsive to more than one signal, as shown in the specification, where the signal from the RF pickup coil is combined with the error signal to allow a correction to be made.

Further, certain situations are evident where the "object to be heated" is a specific zone in the reactor, rather than an object such as the semiconductor wafer. Thus, for gas reactors requiring certain temperature minimums or maximums, for disassociation or association, the temperature of a given zone in the reactor would be sensed.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention.

I claim:

1. A system for obtaining a desired temperature of an object being heated in a reactor, comprising:
 a reactor;
 energy input means for heating said reactor;
 thermocouple sensing means located adjacent said reactor to sense a gross temperature related to the internal temperature of said reactor, said thermocouple sensing means generating a voltage related to the temperature sensed;
 optical sensing means focused upon the object to be heated within said reactor, said optical sensing means generating a voltage related to the temperature of the object upon which it is focused;
 means for generating a first set point voltage, related to the temperature at which it is desired to heat the object being heated;
 first comparing means for comparing said first set point voltage with said optically sensed voltage, the difference between said first set point voltage and said optically sensed voltage constituting a first error voltage;
 means for generating a *K*-factor comprising the sum of the prior occurring *k*-factor and the prior occurring first error voltage, the initial *K*-factor at time equal to zero being made equal to said thermocouple sensed voltage at time equal to zero;
 second comparing means for adding said first error voltage and said *k*-factor, the sum constituting a second set point voltage;
 third comparing means for comparing said second set point voltage with said thermocouple sensed voltage, the voltage difference constituting a second error voltage; and
 heat supply control means for controlling the energy input to said reactor, said heat supply control means responsive to said second error voltage to adjust the energy input to said reactor to control the temperature of the object being heated.

2. The system of claim 1 wherein said heating means is an RF heating unit.

3. The system of claim 1 wherein said thermocouple sensing means comprises a thermocouple embodied in a dummy block located externally adjacent said reactor.

4. The system of claim 2 wherein said thermocouple sensing means comprises a thermocouple embodied in a dummy block located externally adjacent said reactor and between the induction coils of said RF heating unit and said reactor.

5. The system of claim 1 wherein said optical sensing means is a radiation pyrometer.

6. The system of claim 1 wherein said optical sensing means is an optical pyrometer.

7. The system of claim 1 wherein said optical sensing means is corrected for emissivity errors.

8. The system of claim 1 including sampling means to allow input from thermocouple sensing means and said optical sensing means to said first and third comparing means to occur at predetermined time intervals.

9. The system of claim 1 including hold means responsive to said second error voltage, to maintain a constant error voltage input signal to said heat supply control means for a predetermined time interval.

10. The system of claim 1 wherein said means for generating said first set point voltage includes means allowing said first set point to be varied to reflect a desired related temperature to which the object is to be heated.

11. The system of claim 1 including means for introducing a desired gas into said reactor.

12. The system of claim 1 wherein said object to be heated comprises a zone within said reactor.

13. A system for obtaining a desired temperature of a semiconductor wafer in an epitaxial growth system wherein said wafer is being heated in a reactor, including means for introducing a desired gas into said reactor, comprising:
 energy input means for heating said reactor;
 thermocouple sensing means located adjacent said reactor to sense a gross temperature related to the internal temperature of said reactor, said thermocouple sensing means generating a voltage related to the temperature sensed;
 optical sensing means focused upon the semiconductor wafer within said reactor, said optical sensing means generating a voltage related to the temperature of the wafer upon which it is focused;
 means for generating a first set point voltage, related to the temperature at which it is desired to heat the wafer being heated;
 first comparing means for comparing said first set point voltage with said optically sensed voltage, the difference between said first set point voltage and said optically sensed voltage constituting a first error voltage;
 means for generating a *K*-factor comprising the sum of the prior occurring *K*-factor and the prior occurring first error voltage, the initial *K*-factor at time equal to zero being made equal to said thermocouple sensed voltage at time equal to zero;
 second comparing means for adding said first error voltage and said *K*-factor, the sum constituting a second set point voltage;
 third comparing means for comparing said second set point voltage with said thermocouple sensed voltage, the voltage difference constituting a second error voltage; and
 heat supply control means for controlling the energy input to said reactor, said heat supply control means responsive to said second error voltage to adjust the energy input to said reactor to control the temperature of the semiconductor wafer being heated.

14. A method for controlling the temperature of an object being heated in a heating system, said heating system comprising a reactor, energy input means for heating said reactor, and heat supply control means responsive to a voltage input to adjust the energy input to said reactor, comprising the steps of:
 placing a thermocouple sensing means adjacent said reactor, to sense a gross temperature related to the internal temperature of said reactor, said thermocouple sensing means generating a voltage related to the temperature sensed;
 focusing an optical sensing means upon the object to be heated within said reactor, said optical sensing means generating a voltage related to the temperature of the object upon which it is focused;
 generating a first set point voltage, related to the temperature at which it is desired to heat the object to be heated;
 comparing said first set point voltage with said optically sensed voltage, the difference between said first set point voltage and said optically sensed voltage constituting a first error voltage;
 generating a *K*-factor comprising the sum of the prior occurring *K*-factor and the prior occurring first error voltage, the initial *K*-factor at time equal to zero being made equal to said thermocouple sensed voltage at time equal to zero;

adding said first error voltage and said *K*-factor, the sum constituting a second set point voltage;

comparing said second set point voltage with said thermocouple sensed voltage, the voltage difference constituting a second error voltage;

entering said second error voltage into said heat supply means, wherein said heat supply control means adjusts the energy input to said reactor to control the temperature thereof.

15. The method of claim 14 wherein said object to be heated comprises a zone within said reactor.

16. A method for determining the error correction necessary to obtain a desired temperature of an object being heated in a reactor, the error correction being used for adjusting the heat input to the reactor, comprising the steps of:

placing a thermocouple sensing means adjacent said reactor, to sense a gross temperature related to the internal temperature of said reactor,

focusing an optical sensing means upon the object within said reactor, to sense a temperature related to the internal temperature of said reactor;

focusing an optical sensing means upon the object within said reactor, to sense a temperature related to the temperature of the object upon which it is focused;

determining a set point temperature to which it is desired to heat the object;

subtracting the optically sensed temperature from the set point temperature to obtain a first temperature error correction;

determining a *K*-factor comprising the sum of the prior occuring *K*-factor and the prior occurring first temperature error correction, the initial *K*-factor at time equal to zero being made equal to said thermocouple sensed temperature at time equal to zero;

adding said first temperature error correction and said *K*-factor, the sum constituting a second set point temperature;

subtracting said thermocouple temperature from said second set point temperature to obtain a final temperature error correction, said final temperature error correction indicating the amount of adjustment needed to heat the input to the reactor to obtain the desired temperature of the object.

PO-1050
(5/69)

# UNITED STATES PATENT OFFICE
# CERTIFICATE OF CORRECTION

Patent No. 3,567,895 (849,029) Dated March 2, 1971

Inventor(s) Oded Paz

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

| | | |
|---|---|---|
| Column 1, | line 21 | That part of the formula reading "1150- should read --1150-1250°C--. |
| | line 47 | "350kHz." should read --350KHz.--. |
| Column 4, | line 58 | " a k" should read --a K--. |
| Column 4, | line 61 | After "signal" delete "$73_2$" and substit therefor --$\theta_2$--. |
| Column 5, | line 25 | "at time = t" should read --<u>at time = t</u> |
| | line 28 | That portion of the formula which reads "$R_1(t)$" should read --$R_1(t_0)$--. That portion reading "1200°-[illegible]" should read --1200°-1180°--. |
| | line 30 | That portion of the formula reading "$E_1(t)$" should read --$E_1(t_0)$--. |
| | line 31 | That portion of the formula reading "$R_2(t)-\theta_2(ta[0)$" should read --$R_2(t_0)-\theta_2(t_0)$--. |
| | line 34 | "at time = t" should read --<u>at time = t</u> |
| | line 37 | That portion of the formula reading "(ta should read -- $(t_0+T)$--. |
| | line 38 | That portion of the formula reading "(t should read --$(t_0)$ |
| | line 39 | That portion of the formula reading "$(t+T)$ + $k(t_0T)$" should read --$(t_0+T)$ + $k(t_0+T)$--. |
| | line 40 | "$R_2(t+T)$ should read --$R_2(t_0+T)$-- |

PO-1050
(5/69)

# UNITED STATES PATENT OFFICE
# CERTIFICATE OF CORRECTION

Patent No. 3,567,895 Dated March 2, 1971

Inventor(s) Oded Paz PAGE - 2

It is certified that error appears in the above-identified paten and that said Letters Patent are hereby corrected as shown below:

| | |
|---|---|
| Column 6, line 38 | After "poles at" delete "=" and subs therefore --+--. |
| line 44 | Formula 9, that portion reading "(1-z should read --$(1-z^{-1})$--. |
| Column 8, line 76 | Delete "$T_b$')" and substitute therefor --($T_B$')--. |
| Column 9, line 5 | In the formula, that part reading "+αT should read --ΔT--. |
| Column 9, line 4 | After "wall" delete "αT" and substitut therefor --ΔT--. |
| Column 10, line 11 | After "and" delete "4(t)" and substitu therefor --x(t)--. |
| Column 10 | Formula (20) That portion of the form reading "$\frac{d^k X(t)}{dt^k}$" should read --$\frac{d^k x(t)}{dt^k}$-- |

Signed and sealed this 13th day of June 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

PAT-NO: JP411054251A

DOCUMENT-IDENTIFIER: JP 11054251 A

TITLE: TEMPERATURE CONTROLLER

PUBN-DATE: February 26, 1999

INVENTOR-INFORMATION:
NAME

SEKINO, YUTAKA

ASSIGNEE-INFORMATION:
NAME
COUNTRY
MEIDENSHA CORP N/A

APPL-NO: JP09204013

APPL-DATE: July 30, 1997

INT-CL (IPC): H05B006/06

ABSTRACT:

PROBLEM TO BE SOLVED: To provide a temperature controller capable of stably controlling temperature with high accuracy excluding adverse effects from the discontinuous temperature detection amount, when a rapid heating is switched to

a heating for holding a temperature level.

SOLUTION: An induced heating device 10 is used for the anneal heating of a plate joint welding part of a cold rolling line. The induced heating device 10 comprises an inductor 11, a high-frequency power source 12, a radiation thermometer 13 for measuring the temperature of a seam part, and a PC (programmable controller) 14 for performing temperature control from the temperature rise to holding of temperature. PC 14 inputs a measured temperature θr, a target temperature θs, a temperature rising set voltage V<SB>1</SB> and a temperature holding set voltage V<SB>2</SB>, and the voltage E of the high-frequency power source 12 is adjusted to a specific value. Two kinds of settings, that is, the temperature rising set voltage V<SB>1</SB> and the temperature holding set voltage V<SB>2</SB> can be switched on through (θs-α) °C. After the switching, the PID control is executed after the time to reach the temperature balance condition has passed. αis calculated from α=aX<SP>β</SP>+b [where X is the temperature rising output, X=V<SB>1</SB>, (a) is a coefficient, (b) is a constant, and β is 2.0 in the case of voltage].